Fire in the Far North: tundra and boreal forest

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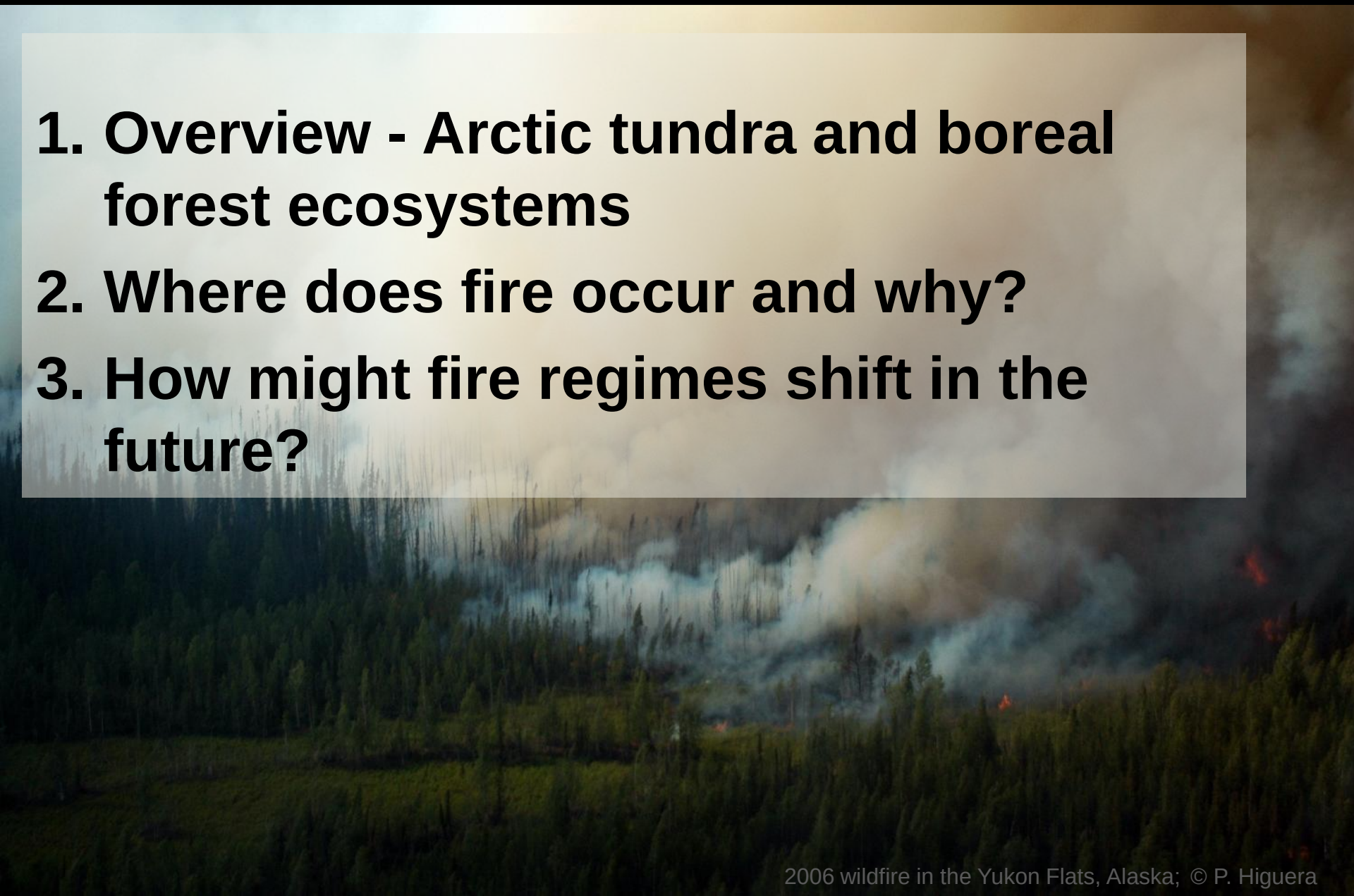
College of Natural Resources

2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

Outline

1. Overview - Arctic tundra and boreal forest ecosystems
2. Where does fire occur and why?
3. How might fire regimes shift in the future?

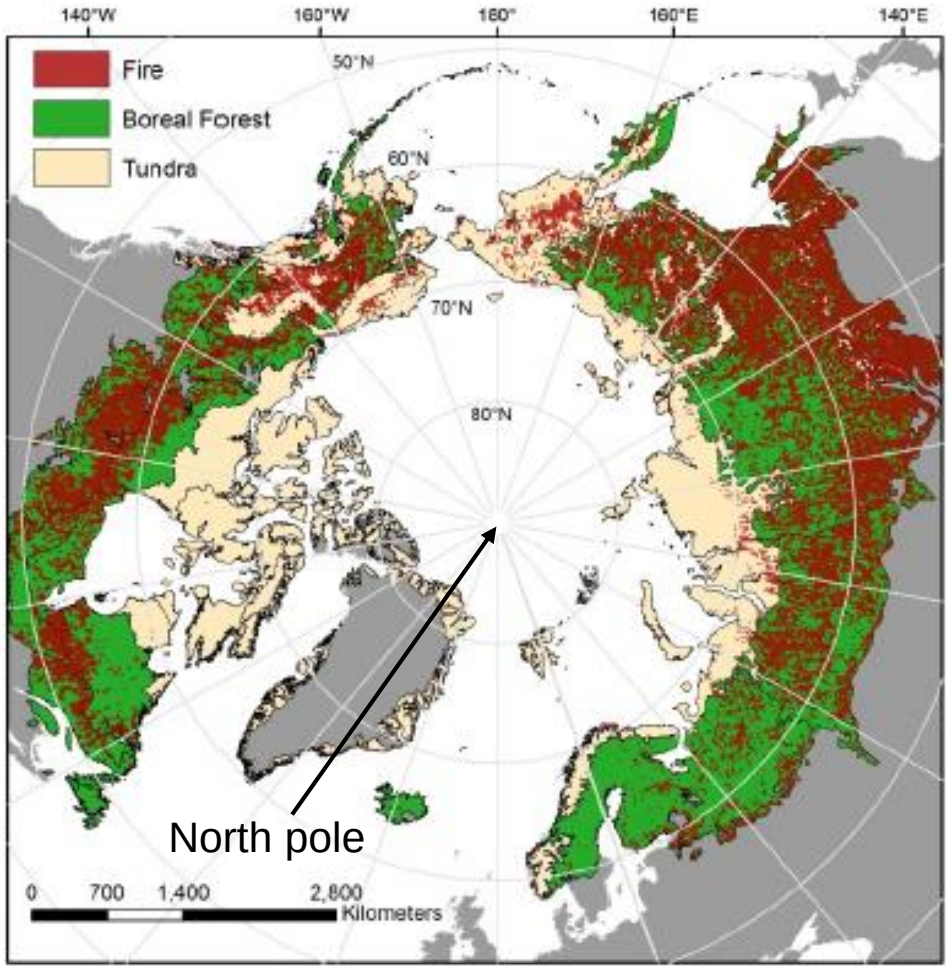


2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

Where is the Far North?

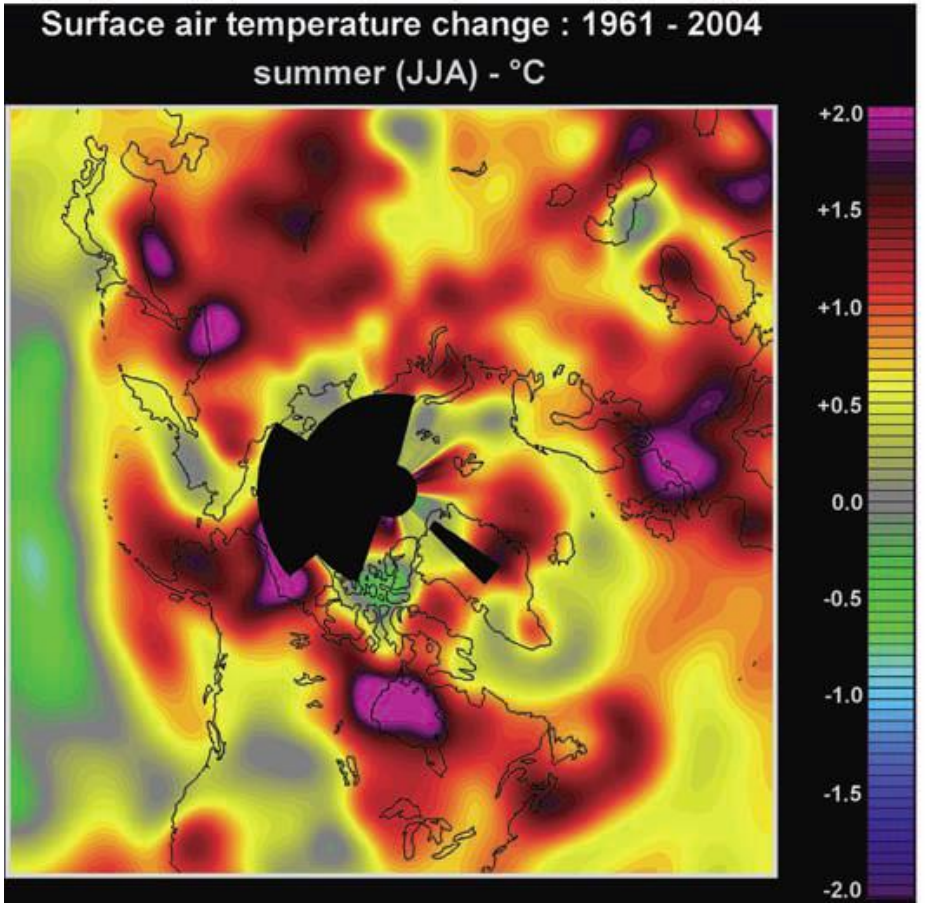
Distribution of boreal forests and tundra ecosystems

- **Majority of land area above 55° N**
- **Characterized by cool, short summers and long, cold winters**



Why study the Far North?

- **Faster rates of climate change relative to the rest of the globe**
- **Highly sensitive to climate change, due to positive feedbacks**(e.g., Chapin et al. [2005], McGuire et al. [2004])



Chapin *et al.* 2005 *Science*

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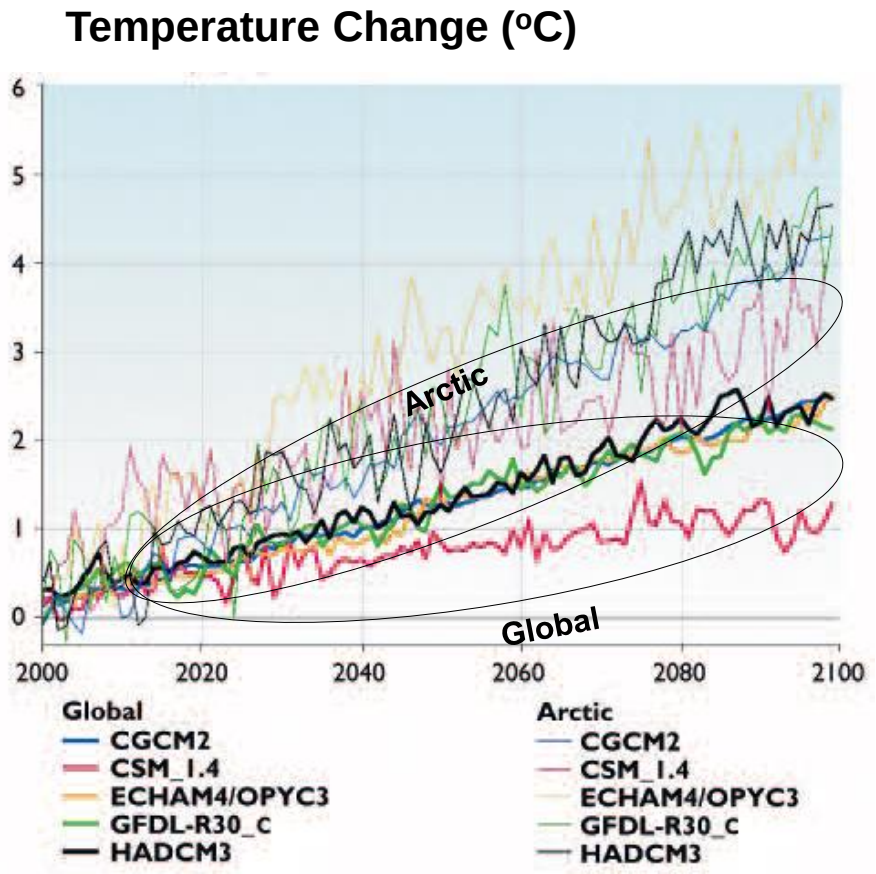
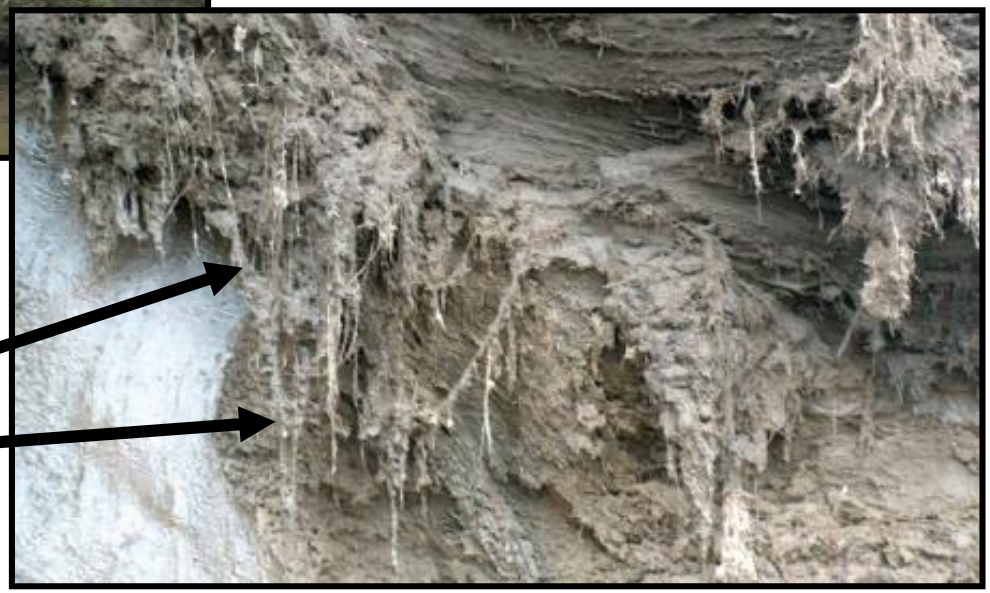


ACIA. 2004

Why study the Far North?

Permafrost: Cold climate → Frozen soils



30,000 year old grass

Zimov *et al.* 2005 *Science*

Permafrost tunnel – Fairbanks, AK

http://uafairbanks.tumblr.com/post/136862651301/engineers-visit-the-us-army-corps-of-engineers

https://www.polartrec.com/files/members/nell-kemp/images/dsc_0403bone-500px.jpg

Why study the Far North?

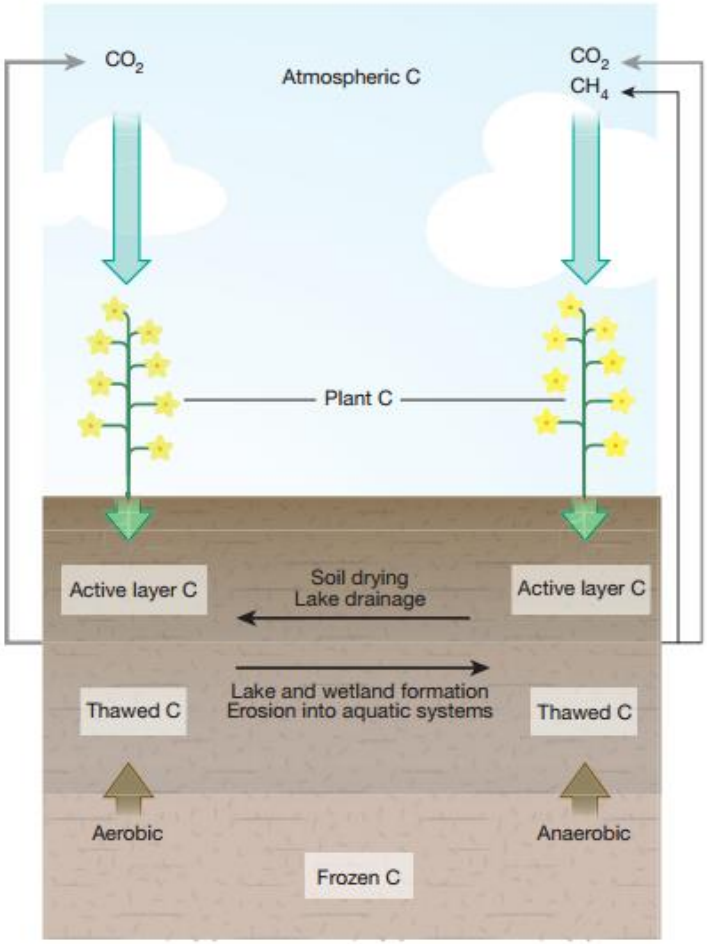
REVIEW

doi:10.1038/nature14338

Climate change and the permafrost carbon feedback

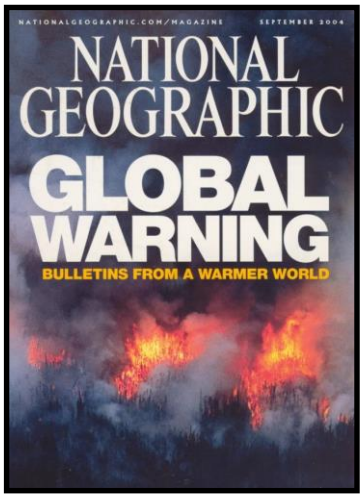
E. A. G. Schuur[1,2], A. D. McGuire[3], C. Schädel[1,2], G. Grosse[4], J. W. Harden[5], D. J. Hayes[6], G. Hugelius[7], C. D. Koven[8], P. Kuhry[7], D. M. Lawrence[9], S. M. Natali[10], D. Olefeldt[11,12], V. E. Romanovsky[13,14], K. Schaefer[15], M. R. Turetsky[11], C. C. Treat[16] & J. E. Vonk[17]

- **Significant proportion of total terrestrial carbon (~50%)**
- **Twice as much carbon in atmosphere**
- **Permafrost thaw → ancient carbon vulnerable to microbial decomposition**



Schuur *et al.* 2015 *Nature*

Why study fire in the Far North?



Carbon loss from an unprecedented Arctic tundra wildfire

Michelle C. Mack[1], M. Syndonia Bret-Harte[2], Teresa N. Hollingsworth[3], Randi R. Jandt[4], Edward A. G. Schuur[1], G & David L. Verbyla[6]

Recent burning of boreal forests exceeds fire regime limits of the past 10,000 years

Ryan Kelly[a], Melissa L. Chipman[b], Philip E. Higuera[c], Ivanka Stefanova[d], Linda B. Brubaker[e], and Feng Sheng Hu[a,b,1]

[a]Department of Plant Biology and [b]Program in Ecology, Evolution, and Conservation Biology, University of Illinois, Urbana, IL 61801; [c]Department of Forest, Rangeland, and Fire Sciences, University of Idaho, Moscow, ID 83844-1133; [d]Limnological Research Center, University of Minnesota, Minneapolis, MN 55455; and [e]School of Environmental and Forest Sciences, University of Washington, Seattle, WA 98195

Articles

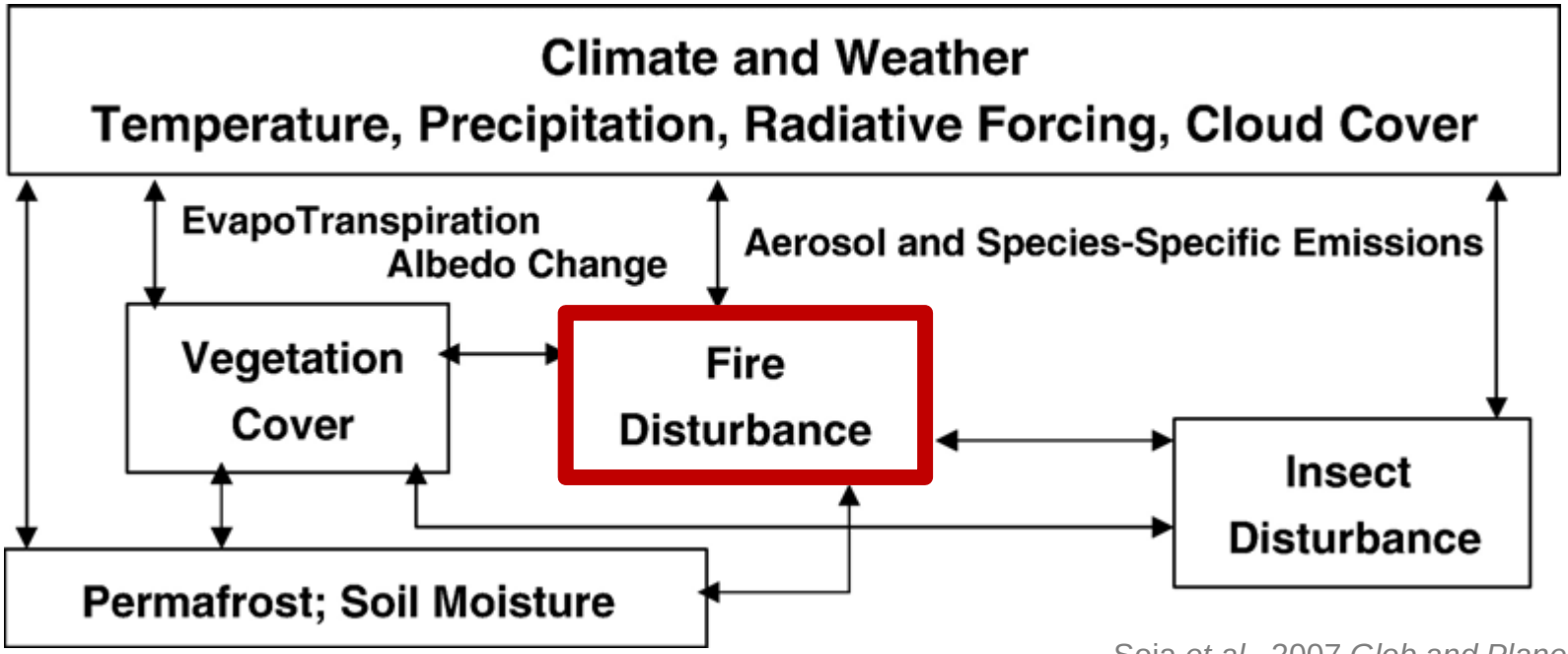
Increasing Wildfire in Alaska's Boreal Forest: Pathways to Potential Solutions of a Wicked Problem

F. STUART CHAPIN III, SARAH F. TRAINOR, ORVILLE HUNTINGTON, AMY L. LOVECRAFT, ERIKA ZAVALETA, DAVID C. NATCHER, A. DAVID McGUIRE, JOANNA L. NELSON, LILY RAY, MONIKA CALEF, NANCY FRESCO, HENRY HUNTINGTON, T. SCOTT RUPP, LA'ONA DeWILDE, AND ROSAMOND L. NAYLOR

esa ECOSPHERE

Simulating the effects of climate change on fire regimes in Arctic biomes: implications for caribou and moose habitat

KYLE JOLY,[1,2,†] PAUL A. DUFFY,[3] AND T. SCOTT RUPP[4]

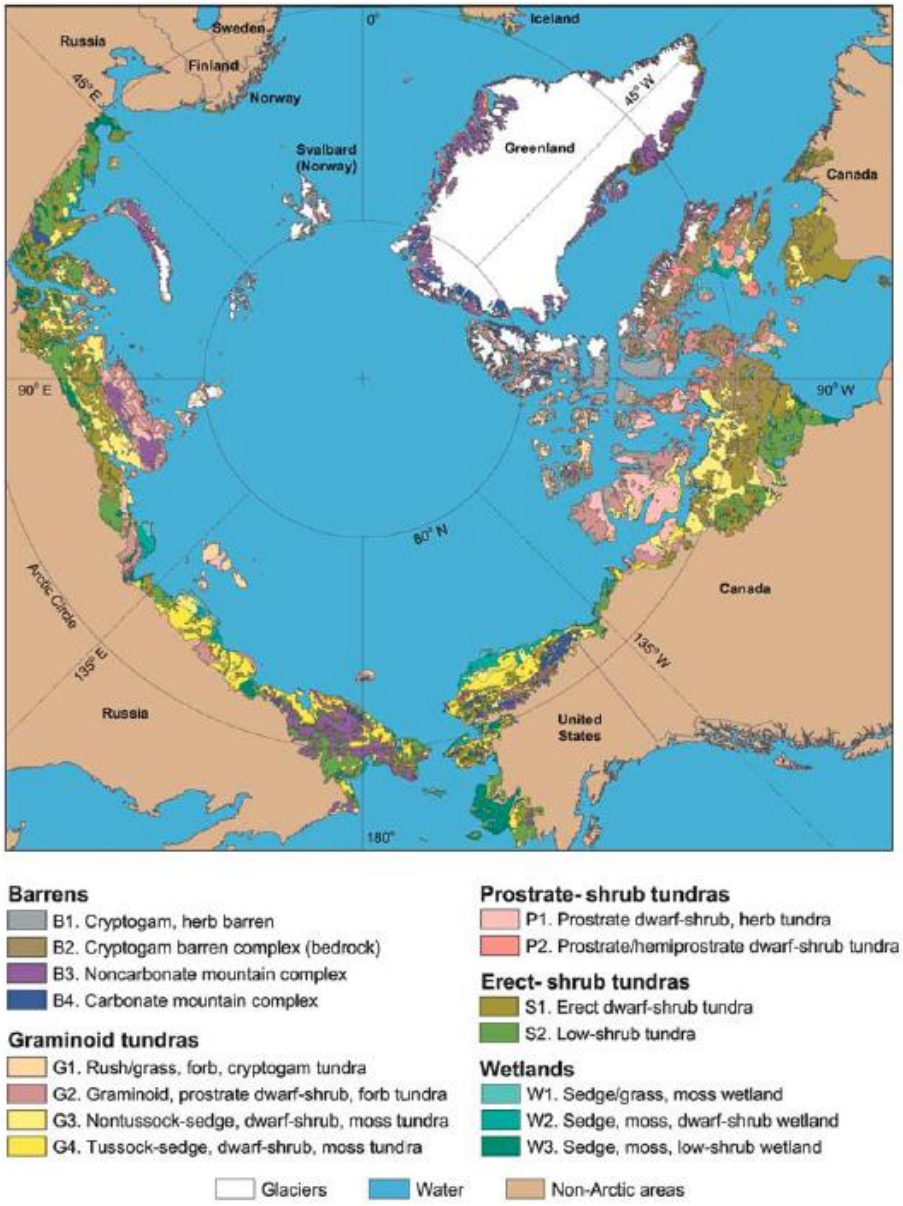


Soja *et al.*, 2007 *Glob and Planetary Chg*

Arctic tundra

Dominant vegetation

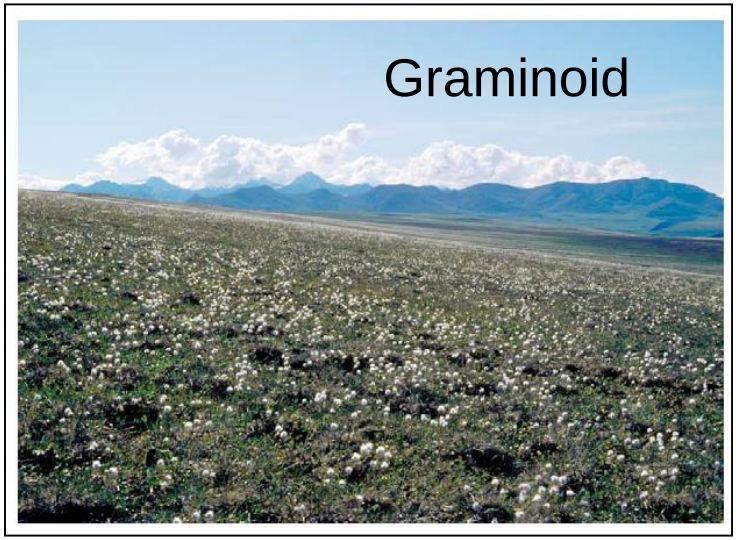
- **Graminoid** (e.g., cotton grass)
- **Prostrate shrub** (e.g., birch, willow, alder)
- **Erect shrub** (e.g., birch, willow, alder)
- **Wetlands**



Walker *et al.* 2005 *J Veg Sci*

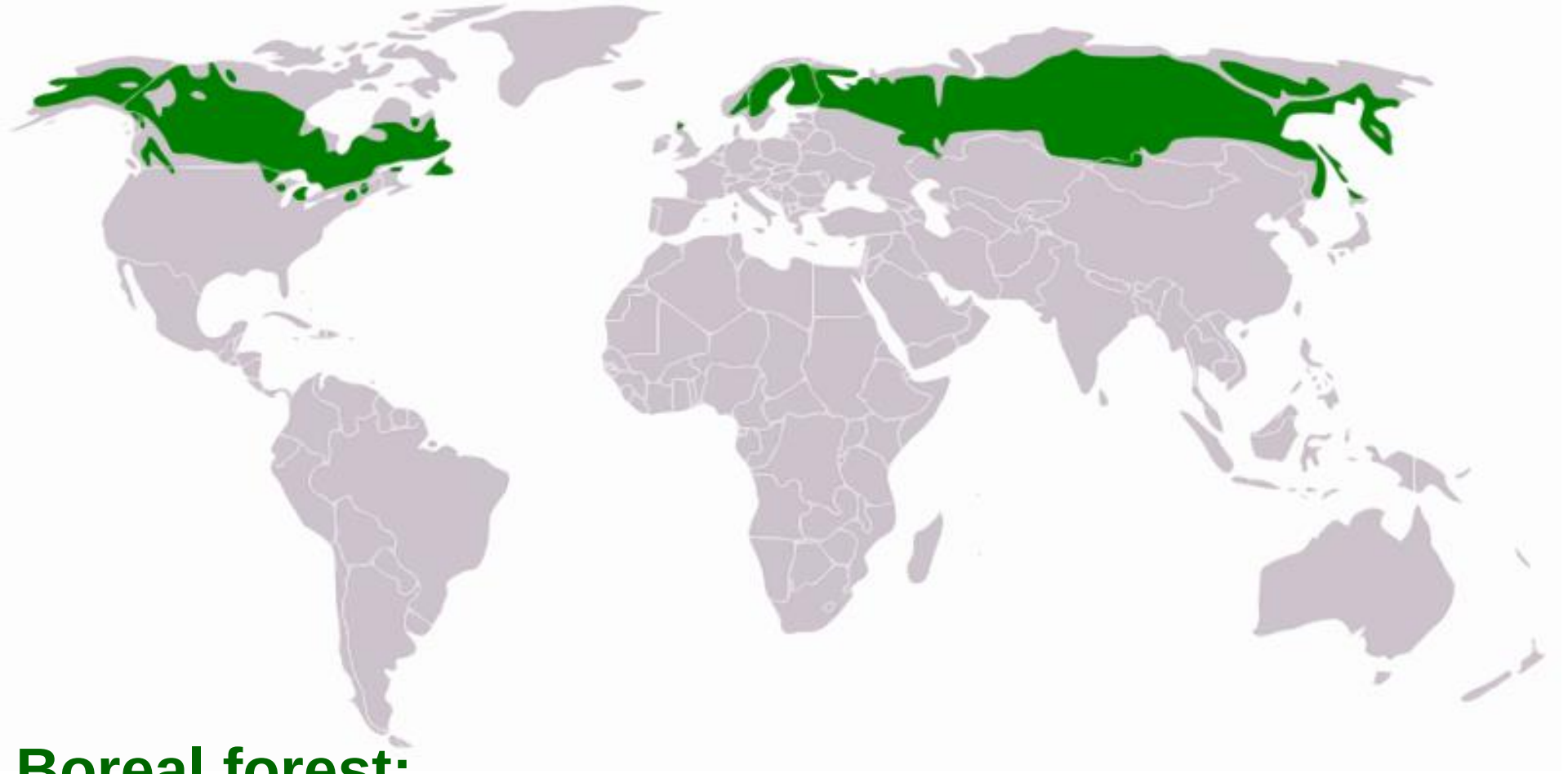
Arctic tundra

Examples -



Walker *et al.* 2005 *J Veg Sci*

Distribution of boreal forest



Boreal forest:

- 14.7 million km^2 (11% terr. Earth)
- Largest terrestrial biome; 29% of world's forest cover

Bonan and Shugart (1998); Wikipedia

Boreal forests

Coniferous species

- **North American boreal forest:** *Picea glauca, Picea mariana*, *Abies balsamea*, *Pinus banksiana*, *Larix laricina*

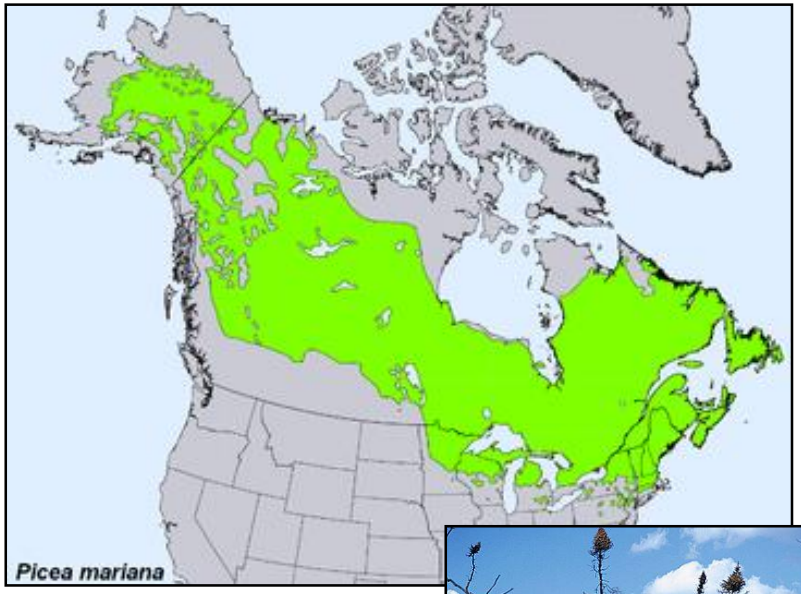
Picea mariana (Wikipedia)

- **Eurasian boreal forest:** *Picea abies, Abies siberica, Pinus sylvestris, Pinus sibirica, Larix sibirica,*

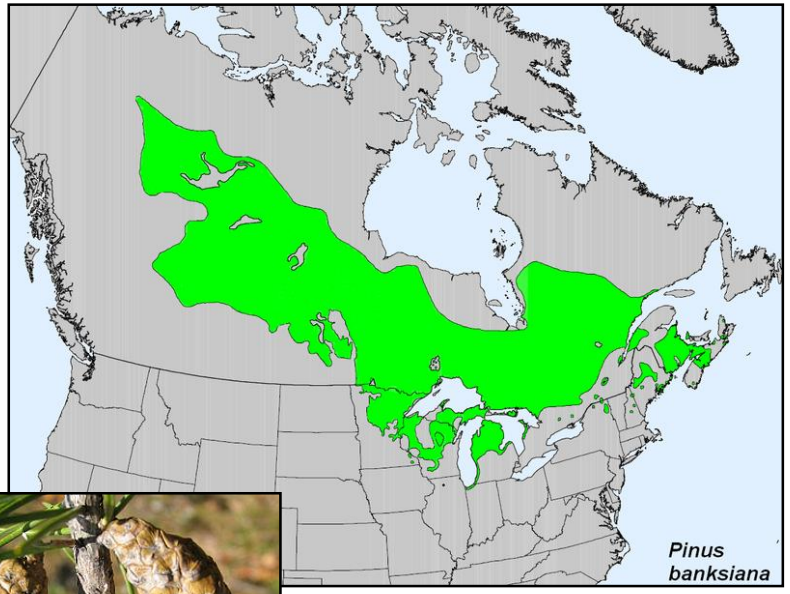
Pinus sylvestris (Wikipedia)

Boreal forests

Species' strategies: (semi-)serotinus cones, aerial seed bank



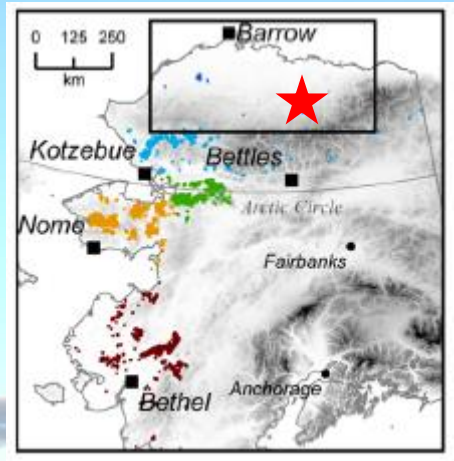
Black spruce



Jack pine

Wikipedia

Arctic tundra



Hu *et al.* 2010 *JGR*

2007 Anaktuvuk River Fire, North Slope, Alaska © P. Higuera, 2011

Ecological impacts of wildfire

Boreal forest

- **Fire is the main driver of carbon cycling in boreal forests**
- **High-severity fires are common in N. America**

Duffy *et al.* 2005 *Eco Apps*

Tundra

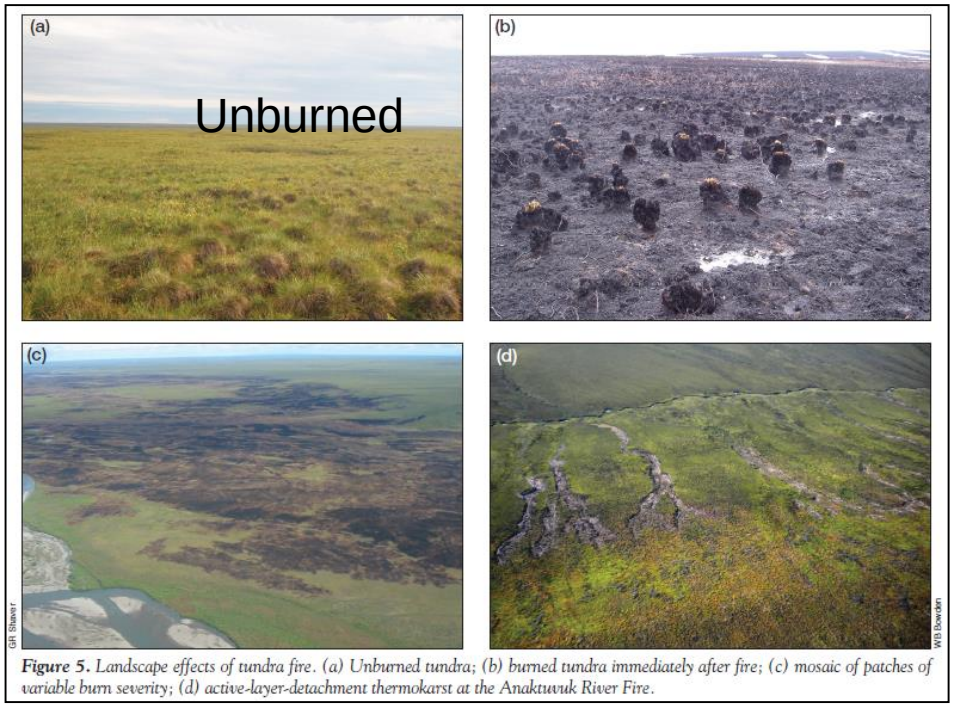


Figure 5. *Landscape effects of tundra fire. (a) Unburned tundra; (b) burned tundra immediately after fire; (c) mosaic of patches of variable burn severity; (d) active-layer-detachment thermokarst at the Anaktuvuk River Fire.*

Hu *et al.* 2015 *Front Ecol Env*

- **Fire can release significant quantities of C**

Ecological impacts of wildfire

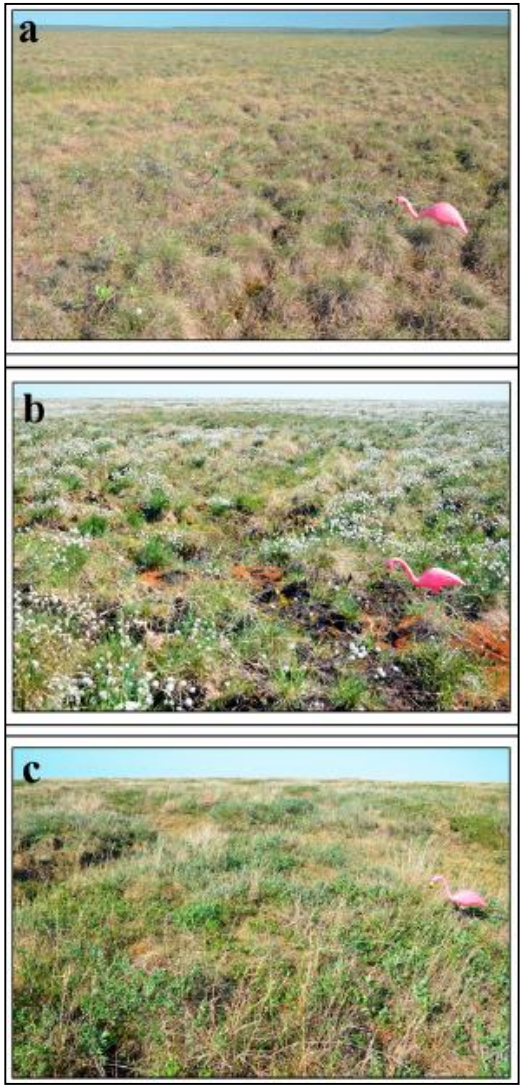
- **Graminoid ⟶ Shrub**

AK Tundra

Unburned

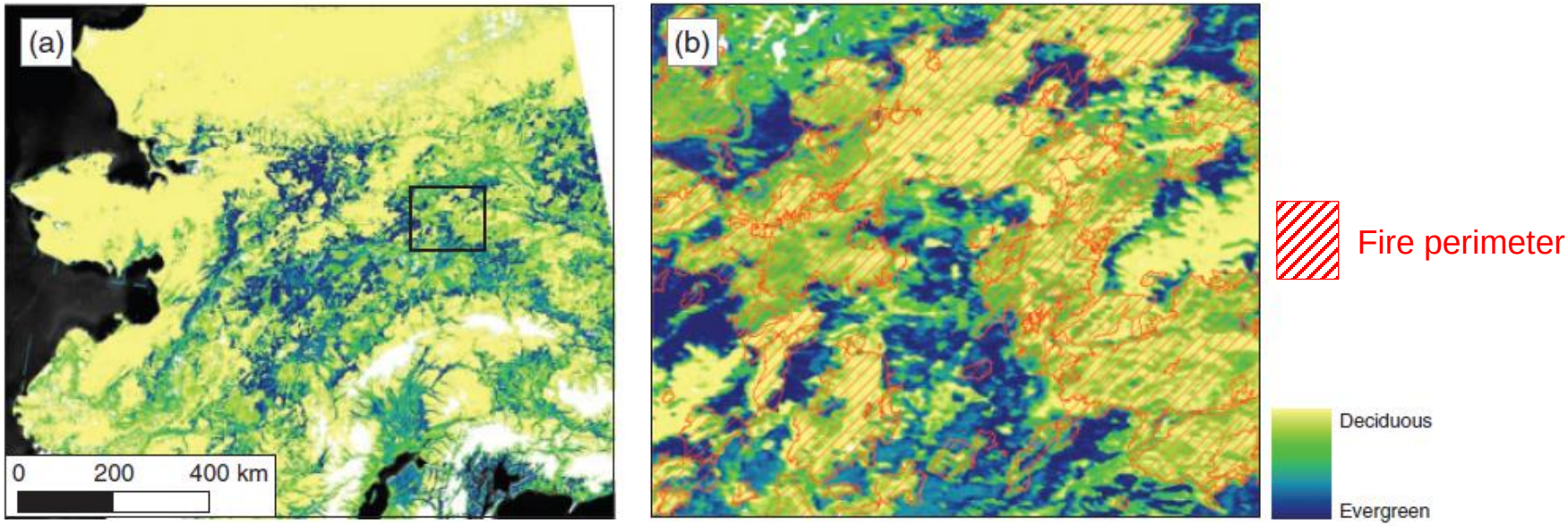
Burned in 2007

Burned in 1993



Jones *et al.* 2013 *JGR*

Boreal forests: post-fire succession



- **In decades following wildfire, deciduous taxa (e.g., *Populus*) dominate succession in boreal forests**

Beck *et al.* 2011 *Glob Change Bio*

Outline

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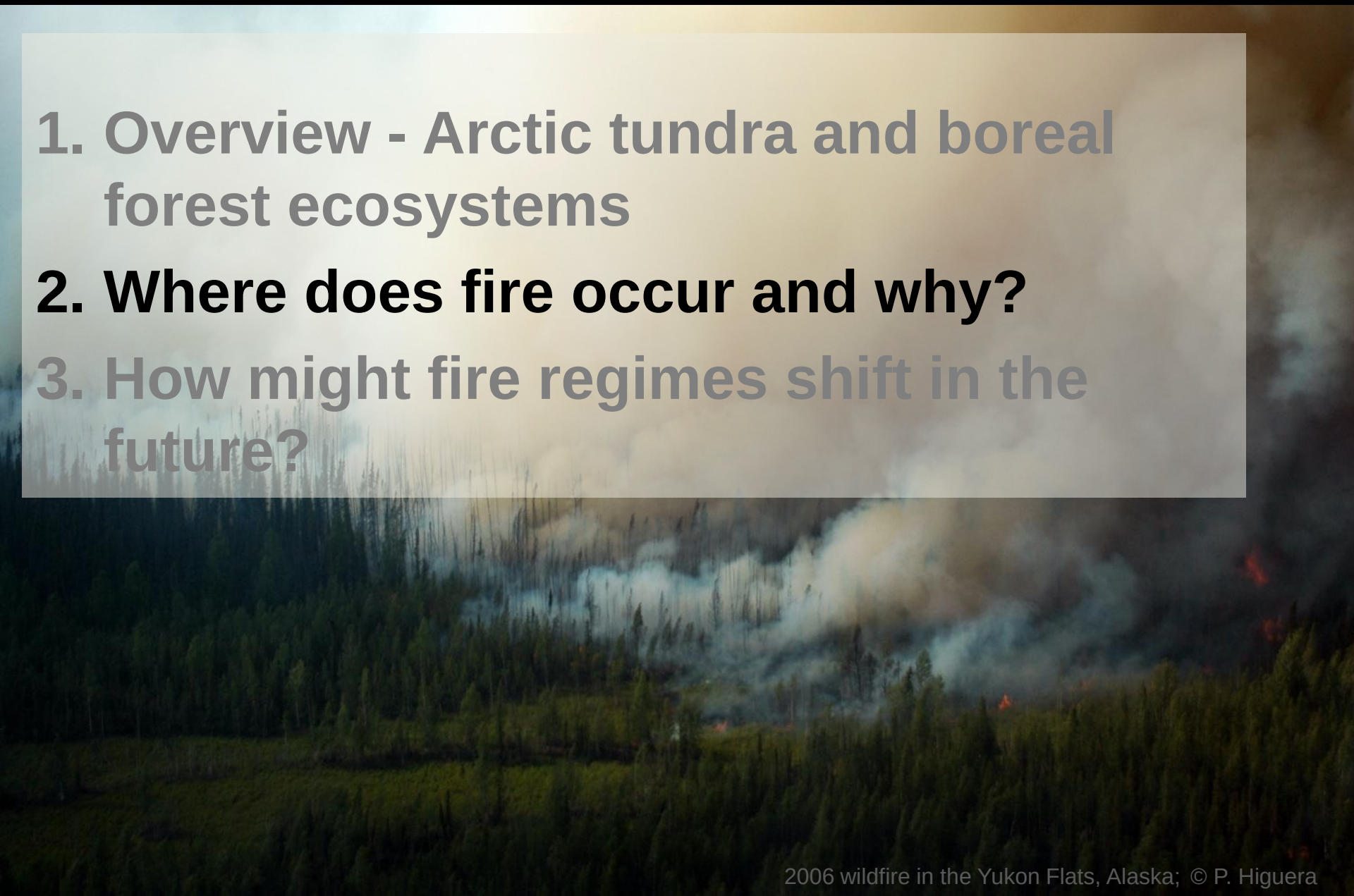


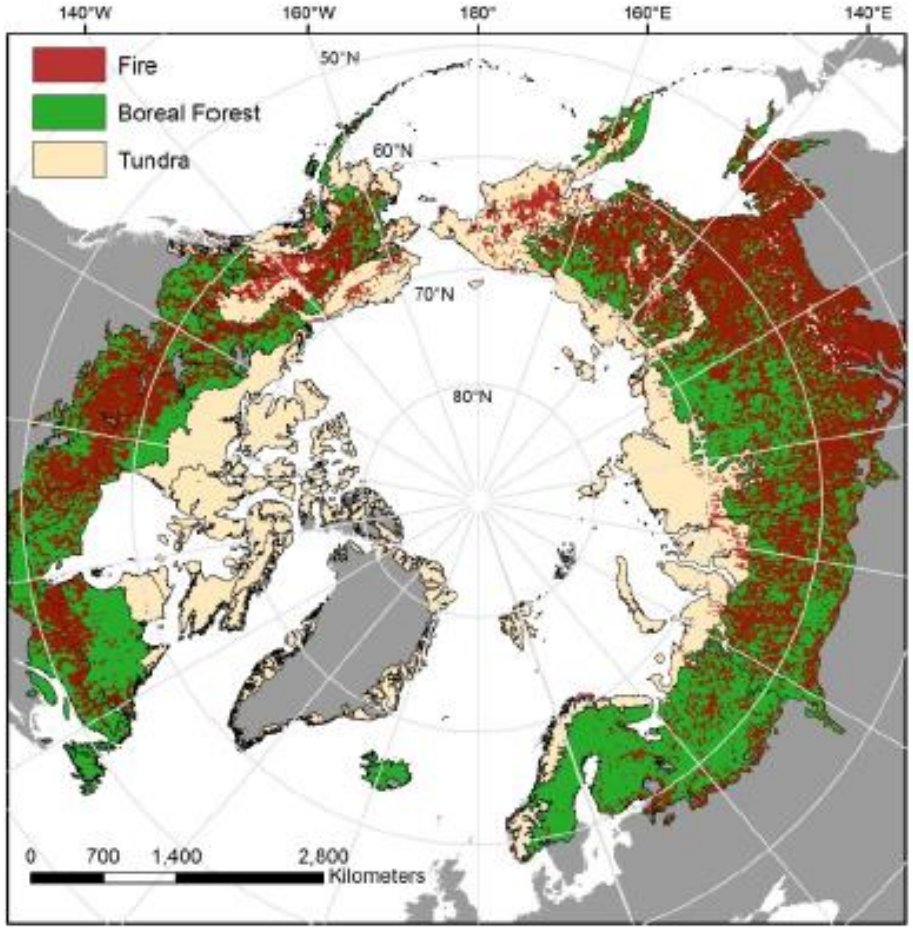
2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

Where does fire occur?

Modern period (1995 – Present)

- **Satellite data highlight continental patterns in wildfire activity**

How do satellites measure fire?

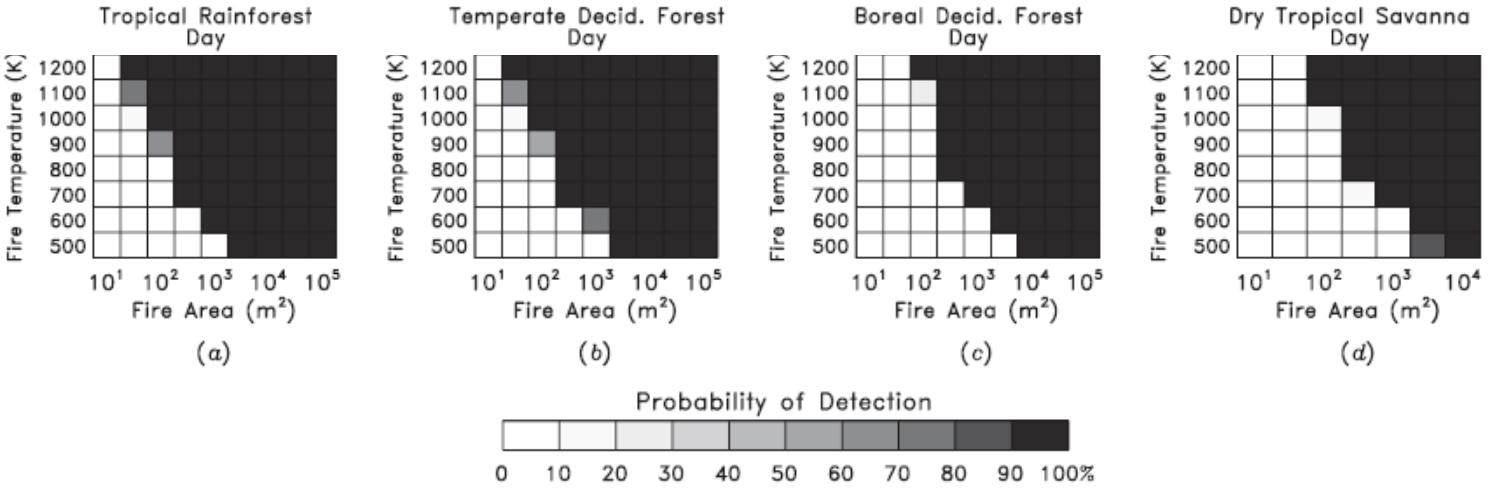


1995 – 2013 GFED4 Data

Brief detour: measuring global fire activity

Active fire detection

- **MODIS Sensor on NASA Terra and Aqua Satellites**
- **Uses thermal infrared portion of EM spectrum to estimate pixel temperature**
- **Fire has a unique thermal "signature" → identify pixels where temperature exceeds a threshold**
- **Able to detect fire at a "sub-grid" level within a pixel, very accurate**



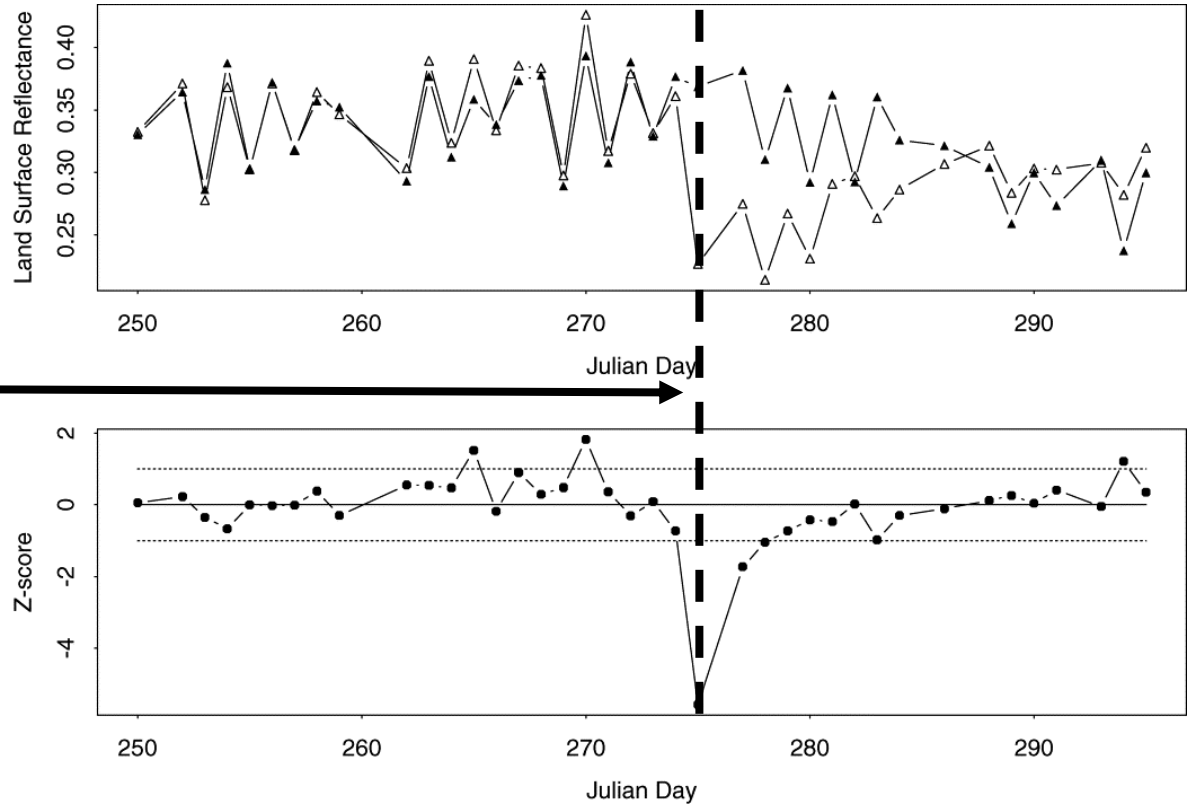
Giglio *et al.* 2003 *Rem Sens Env*

Brief detour: measuring global fire activity

Burned area mapping

- **Uses reflective infrared portion of EM spectrum**
- **Measures time series of land surface reflectance**
- **Persistent changes in land surface reflectance = evidence of burning**

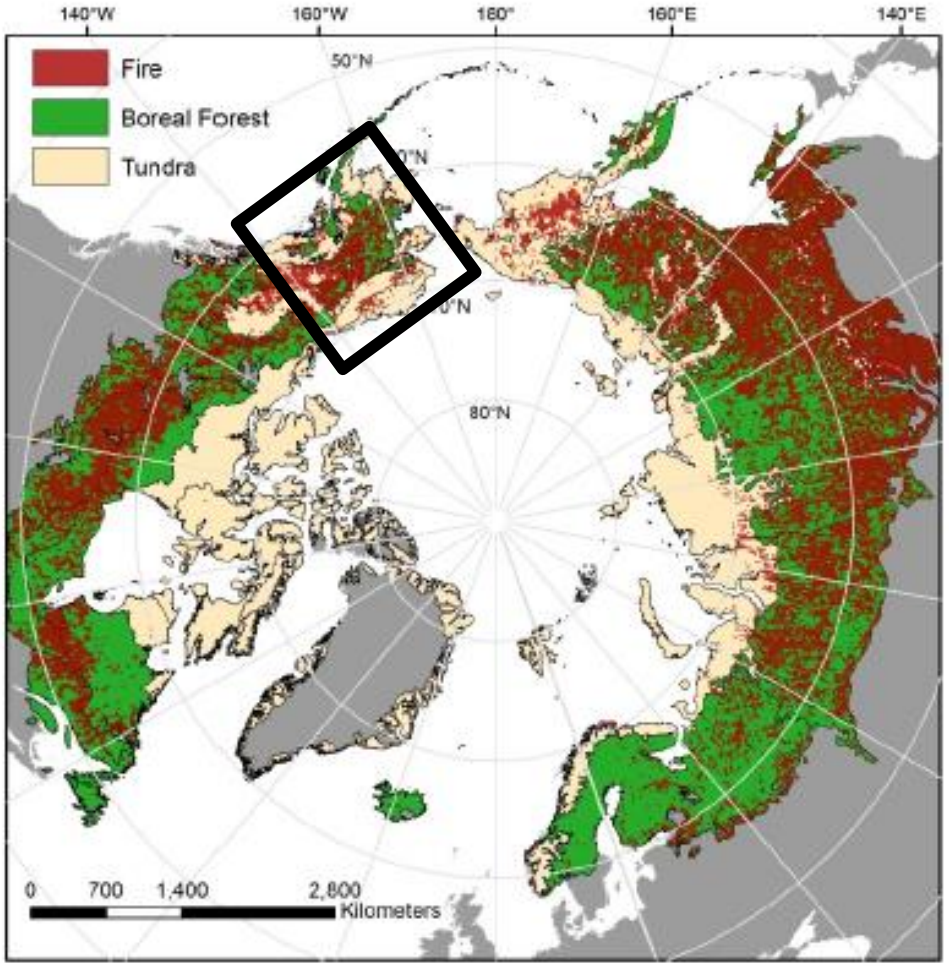
275 - Day of burning



Roy *et al.* 2002 *Rem Sens Env*

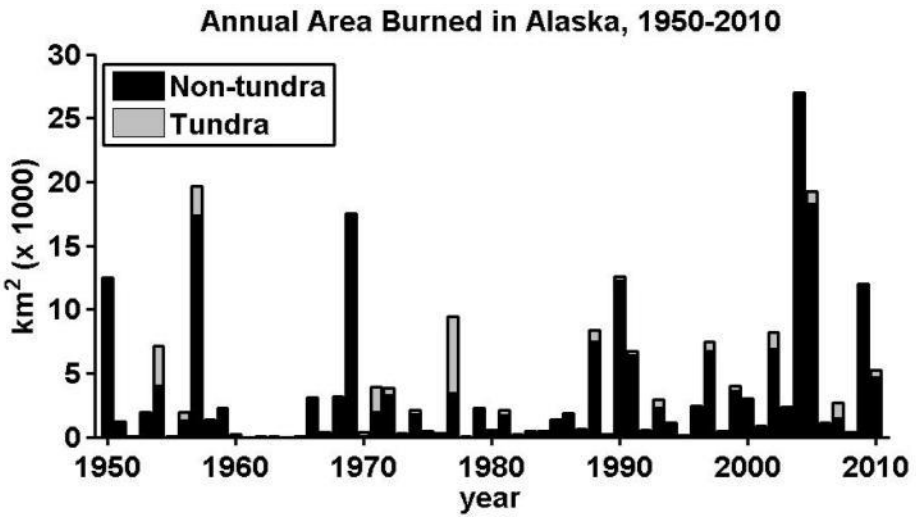
Fire occurrence (1995 – Present)

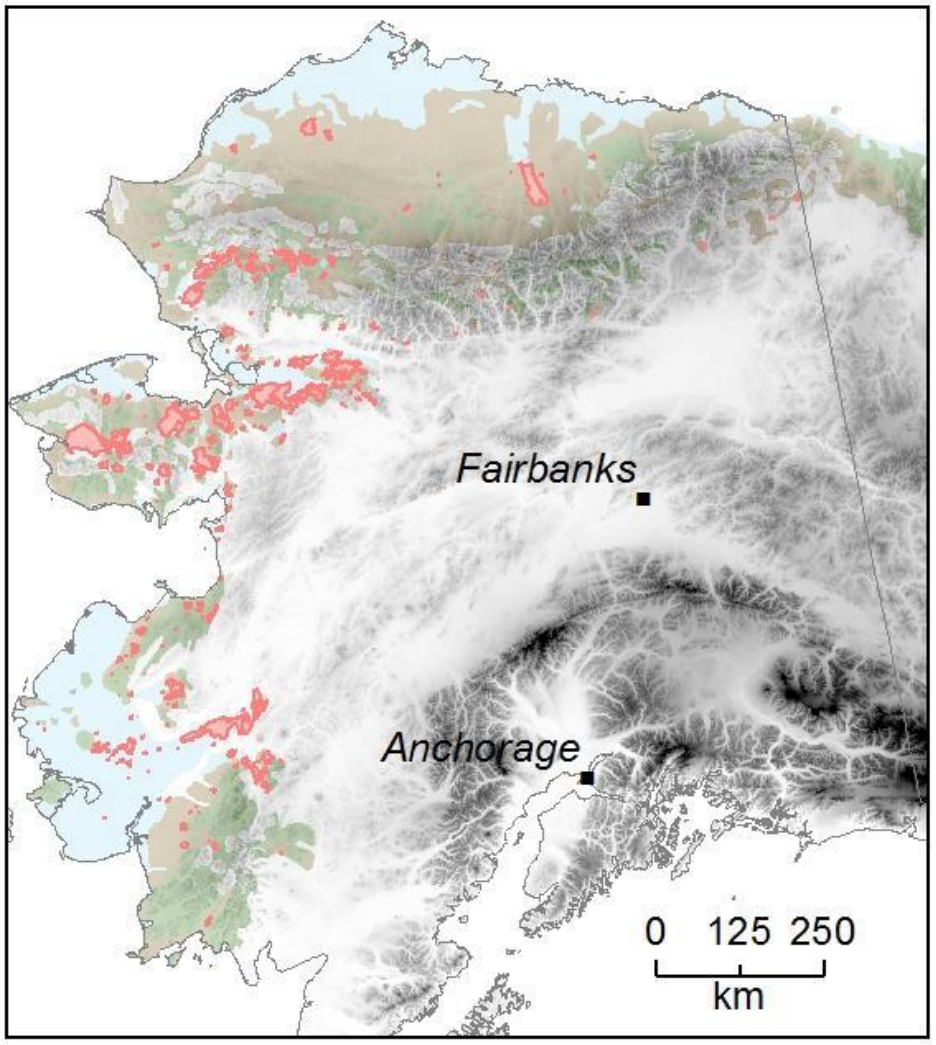
Ex: Burned area data



1995 – 2013 GFED4 Data

Focus on Alaska





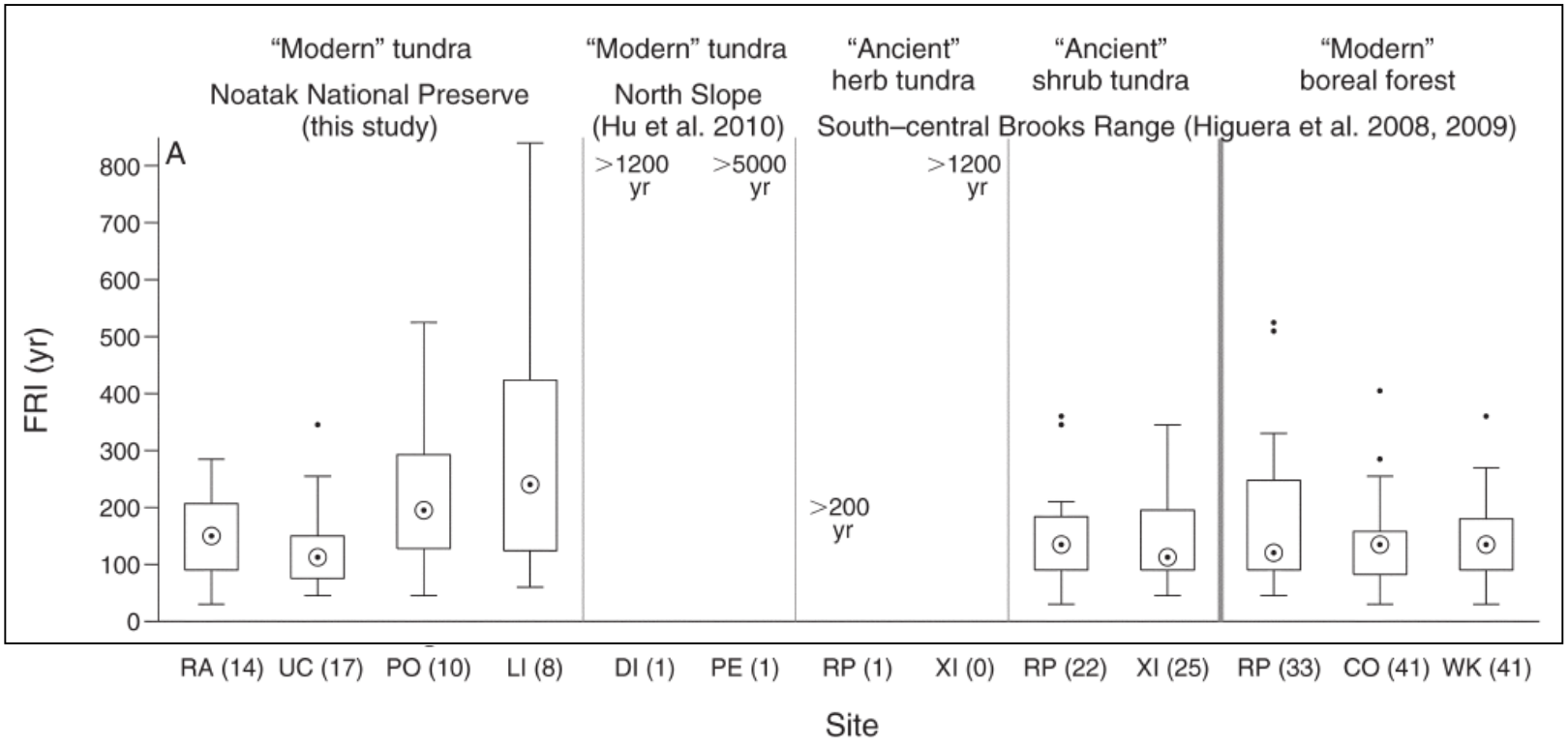
- **≈ 90% area burned in boreal forest**

- **> 2.5 million ha**, 6.2 million acres **burned in tundra (≈ 41,000 ha / yr,** 100,000 acres / yr**)**

- **3315 citations: "boreal forest + fire"**
- **312 citations: "tundra + fire"**

How frequent is fire?

Evidence from paleoecological records



- **Variation in boreal forest and tundra fire activity**

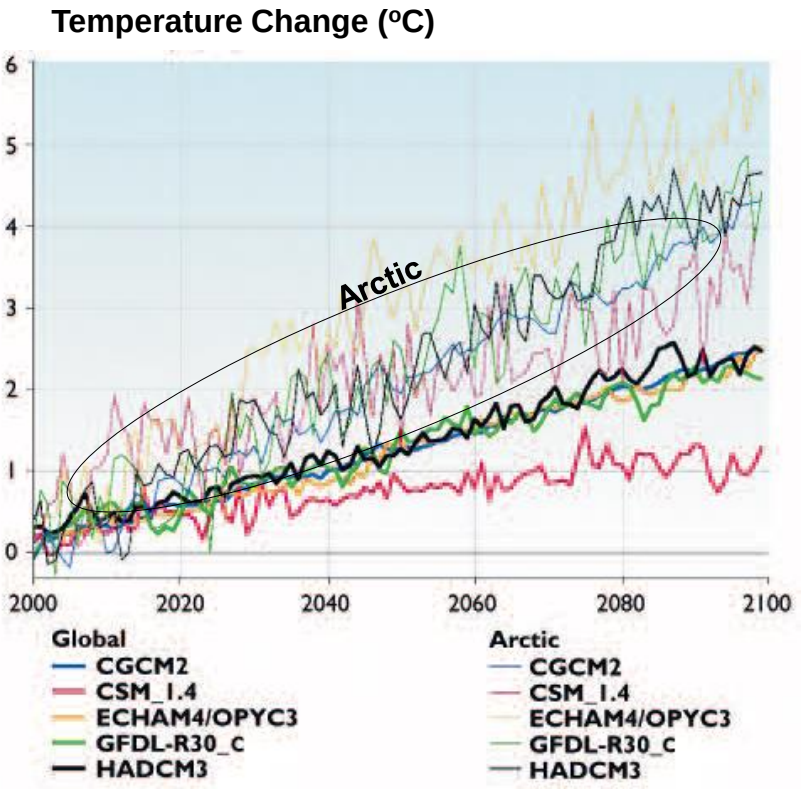
Higuera *et al.* 2011 *Eco Apps*

Wildfire and climate change

What will happen in boreal forest and tundra ecosystems under a changing climate?

How might fire regimes shift in response to climate?

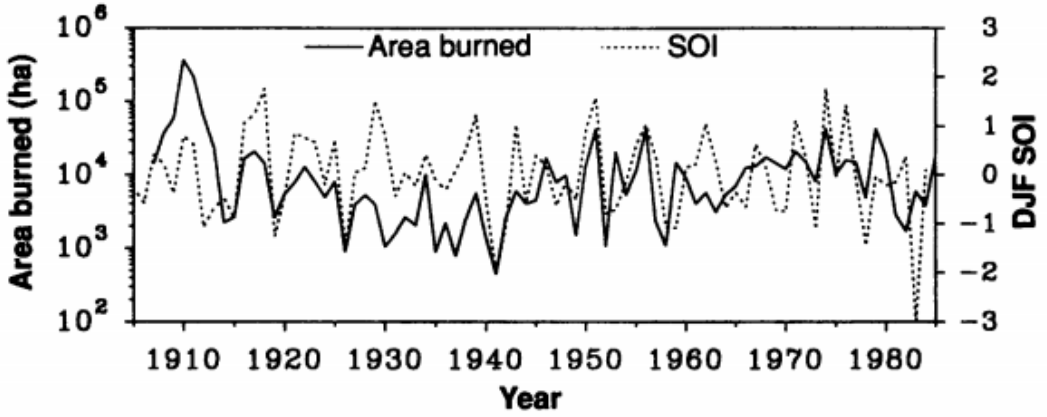
How might these fire-regime shifts occur spatially and temporally?



ACIA. 2004

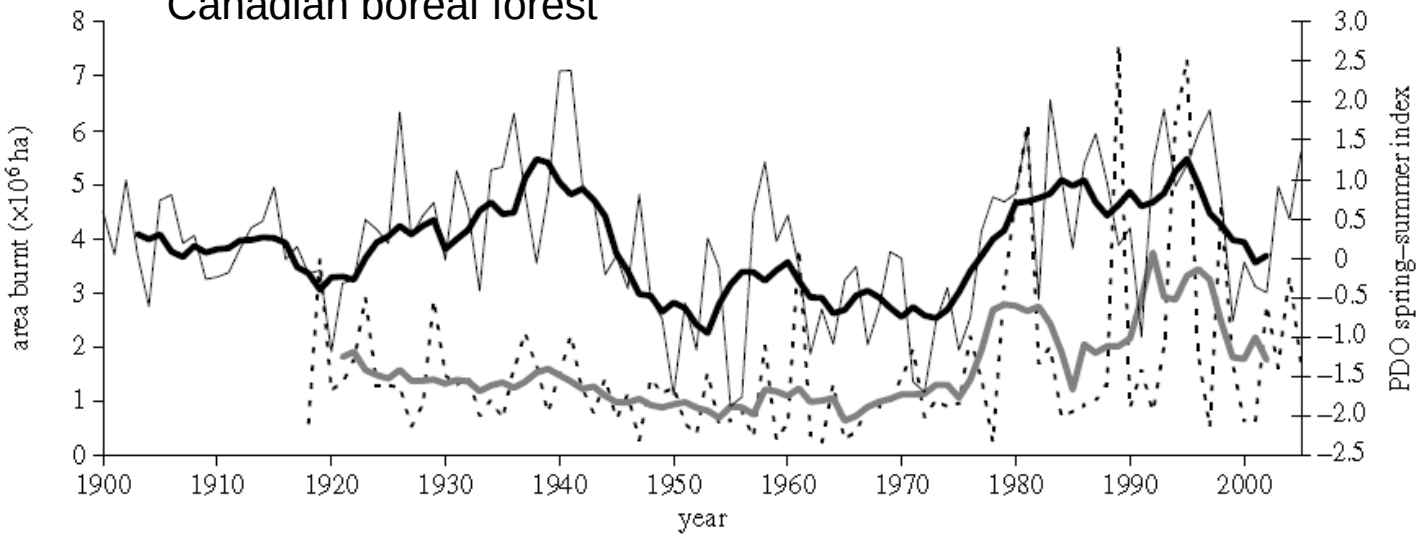
Climate

Fig. 4. Time series of annual area burned (logarithm) in Arizona and New Mexico and mean December through February SOI, 1905 to 1985.



Swetnam & Betancourt 1990 *Science*

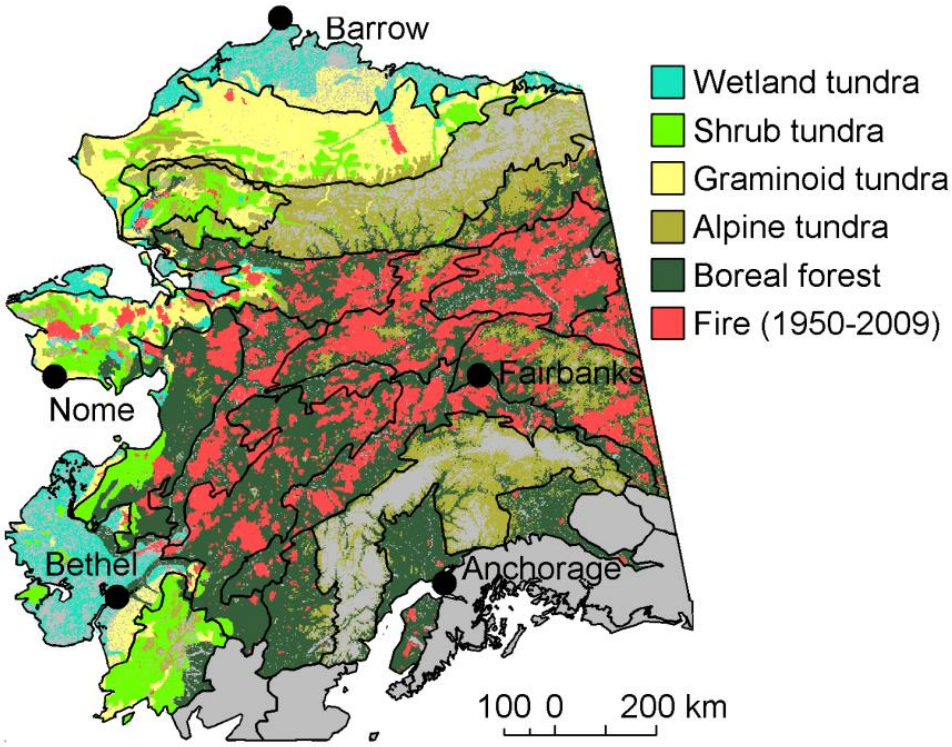
Canadian boreal forest

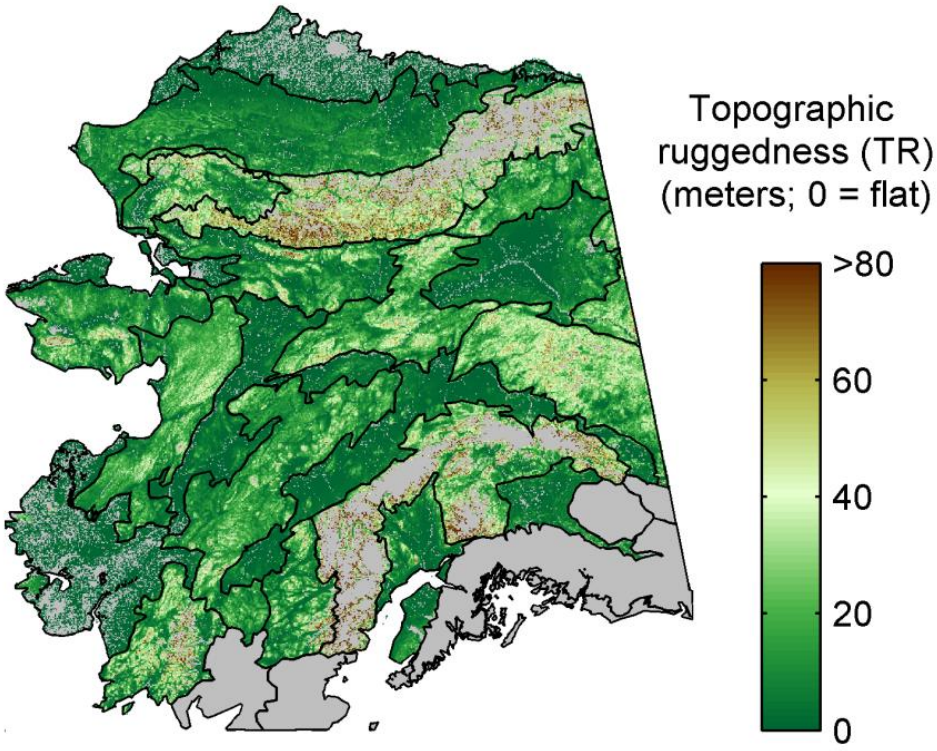


Macias Fauria & Johnson 2008 *Phil. Trans. R. Soc. B*

Explaining patterns in fire activity

Q: What controls this spatial pattern?



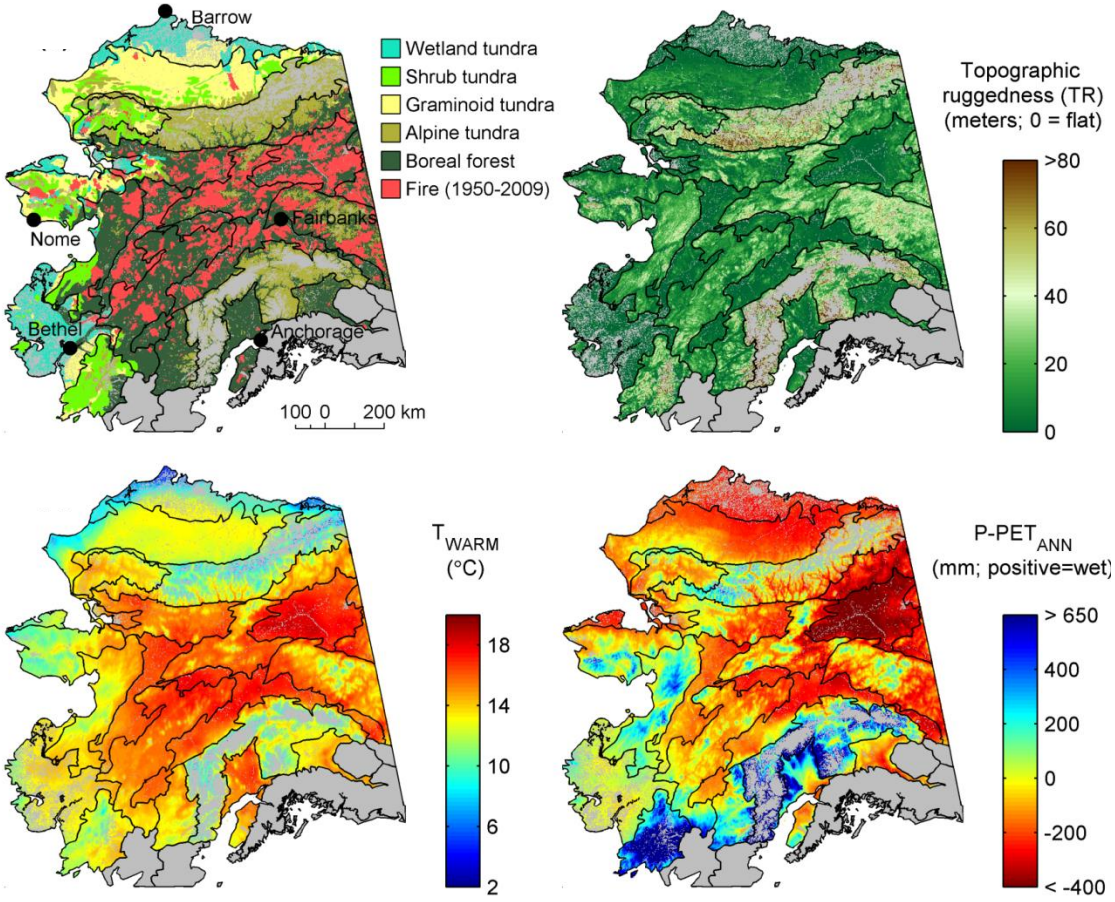


Young *et al. In Revision*

Quantifying fire-regime controls

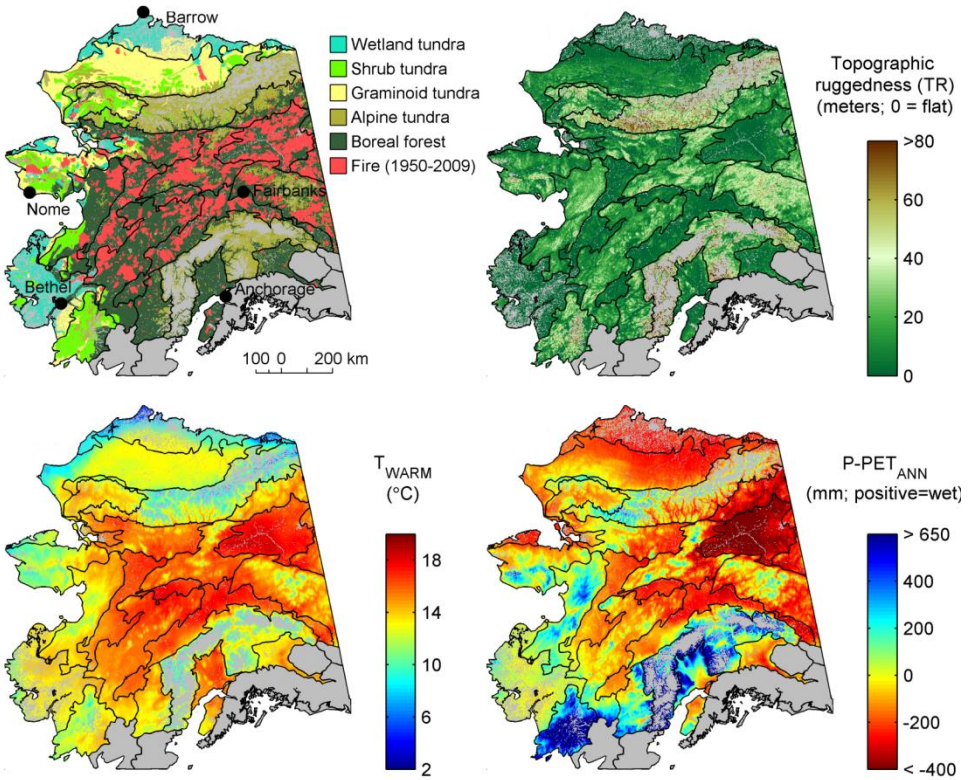
Statistical modeling

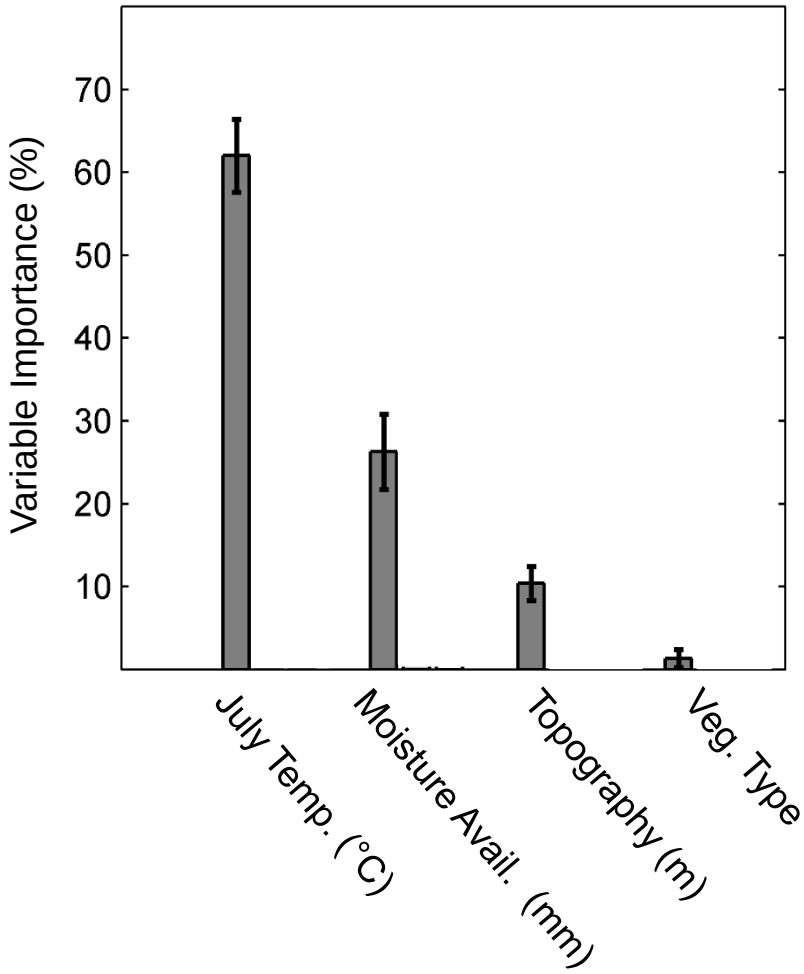
Fire = *ƒ*(climate, veg, topography)



Fire-regime controls

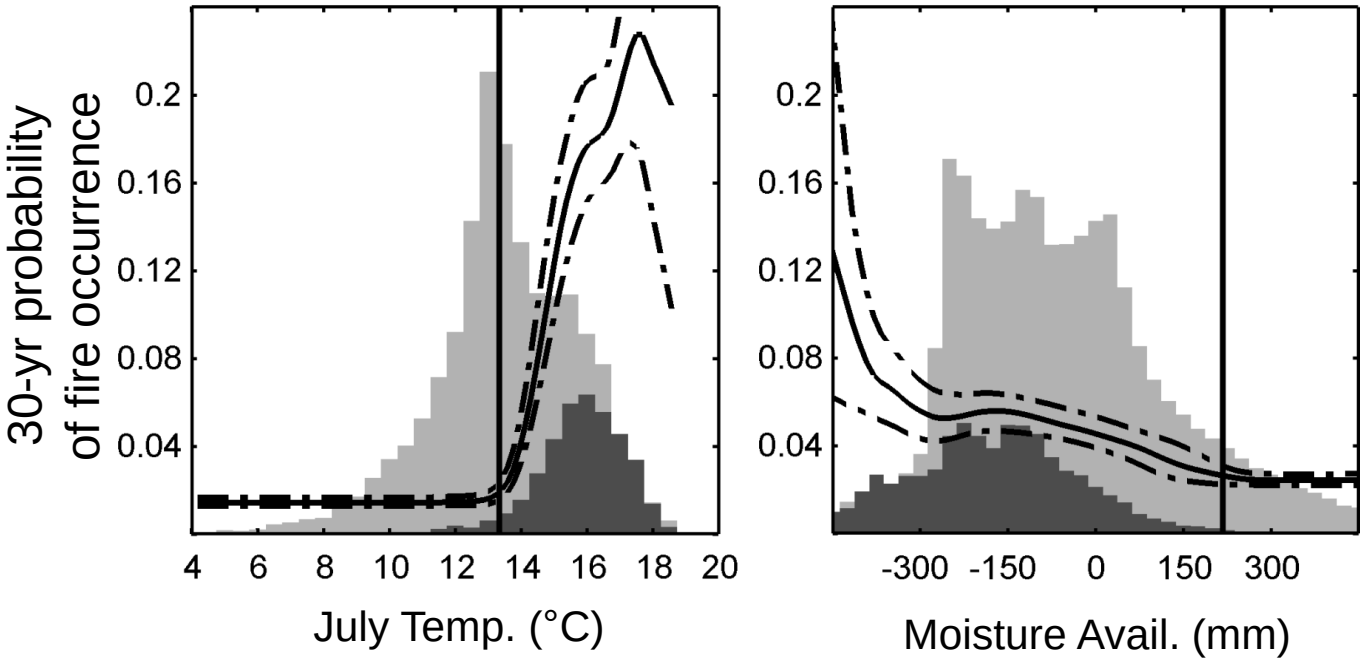
- **Temperature and moisture most important**





Fire-regime controls

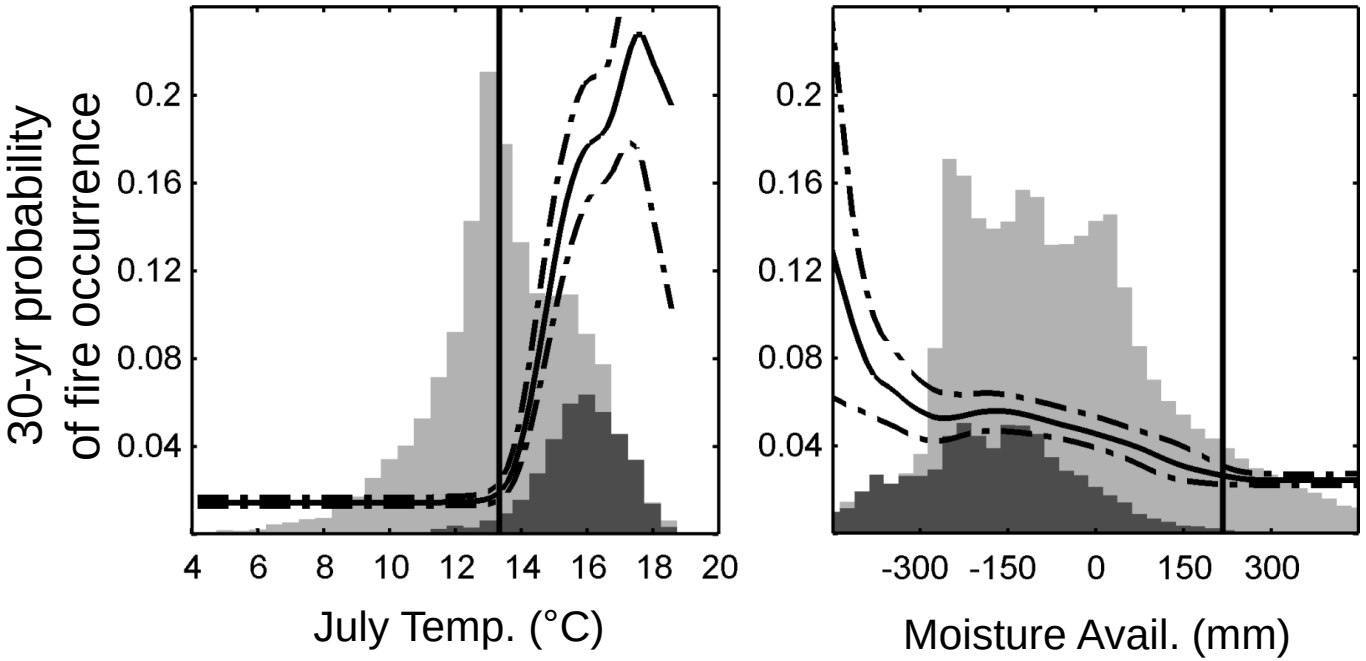
Climatic controls



Young *et al. In Revision*

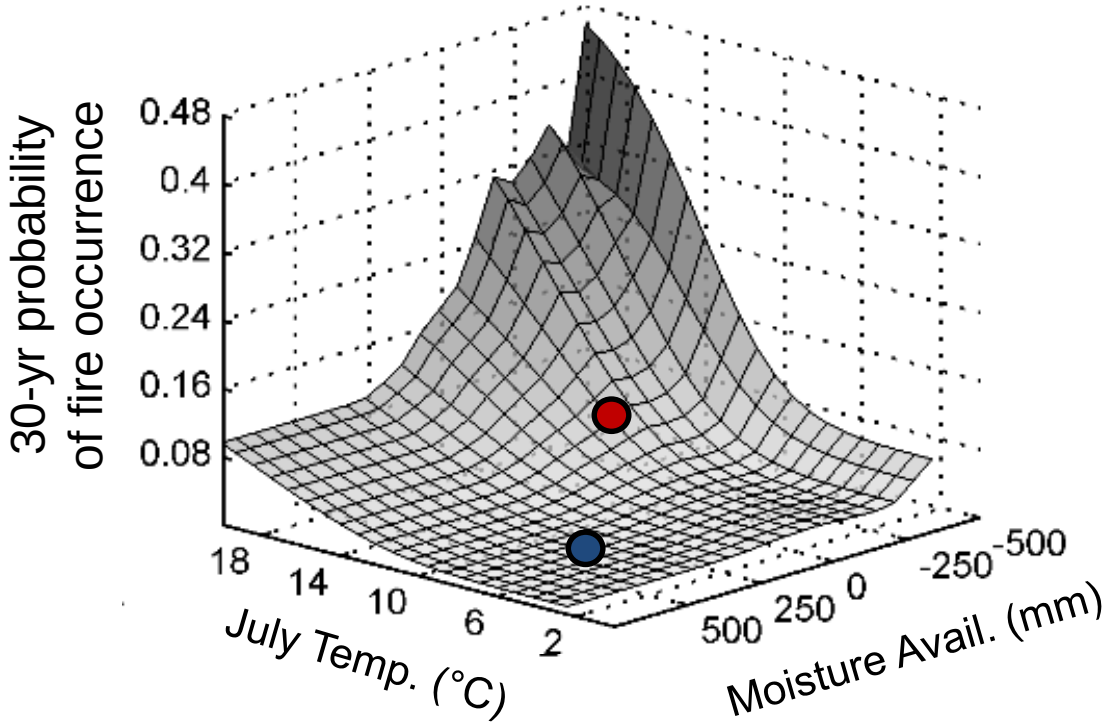
Fire-regime controls

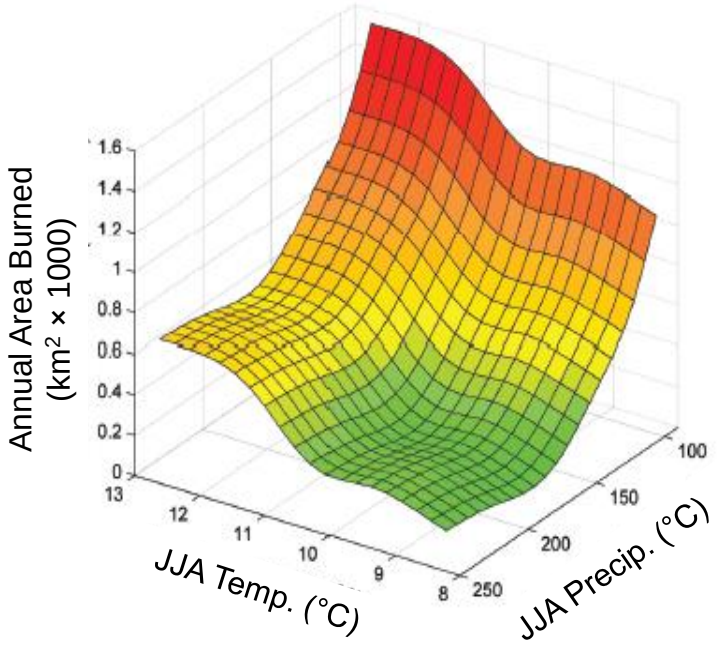
Why do these thresholds matter?



Young *et al. In Revision*

Climatic interactions





- **Different levels of vulnerability to climate-induced shifts in fire activity**

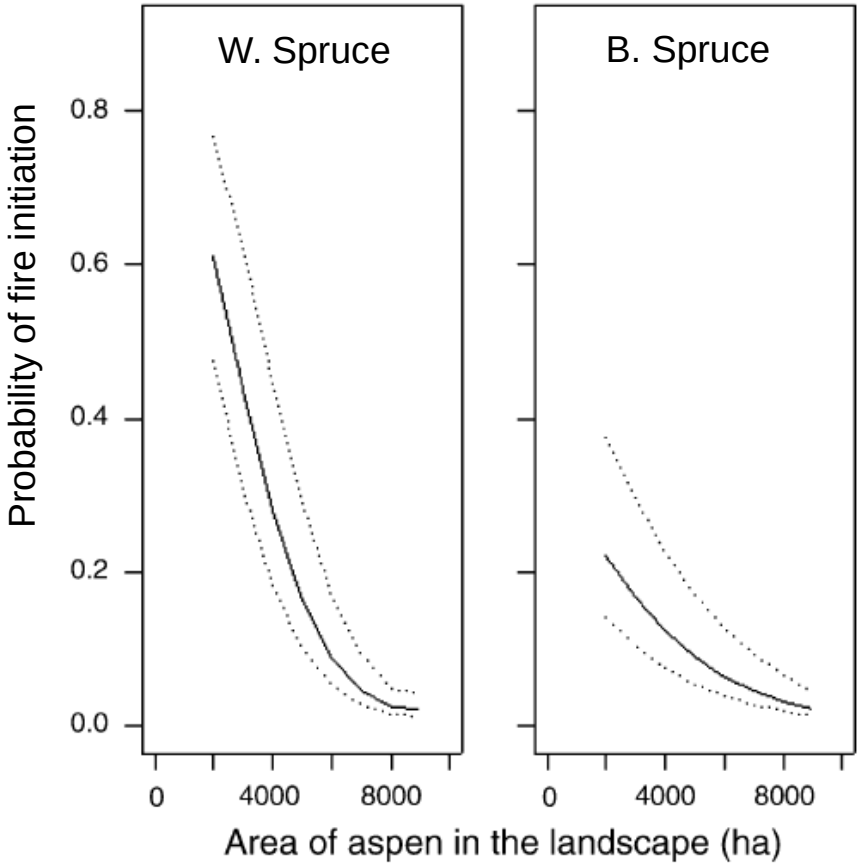
Young *et al. In Revision*

Controls of wildfire – vegetation

Can. Boreal forest

Aspen

Spruce



Krawchuk *et al.* 2006 *Ecology*

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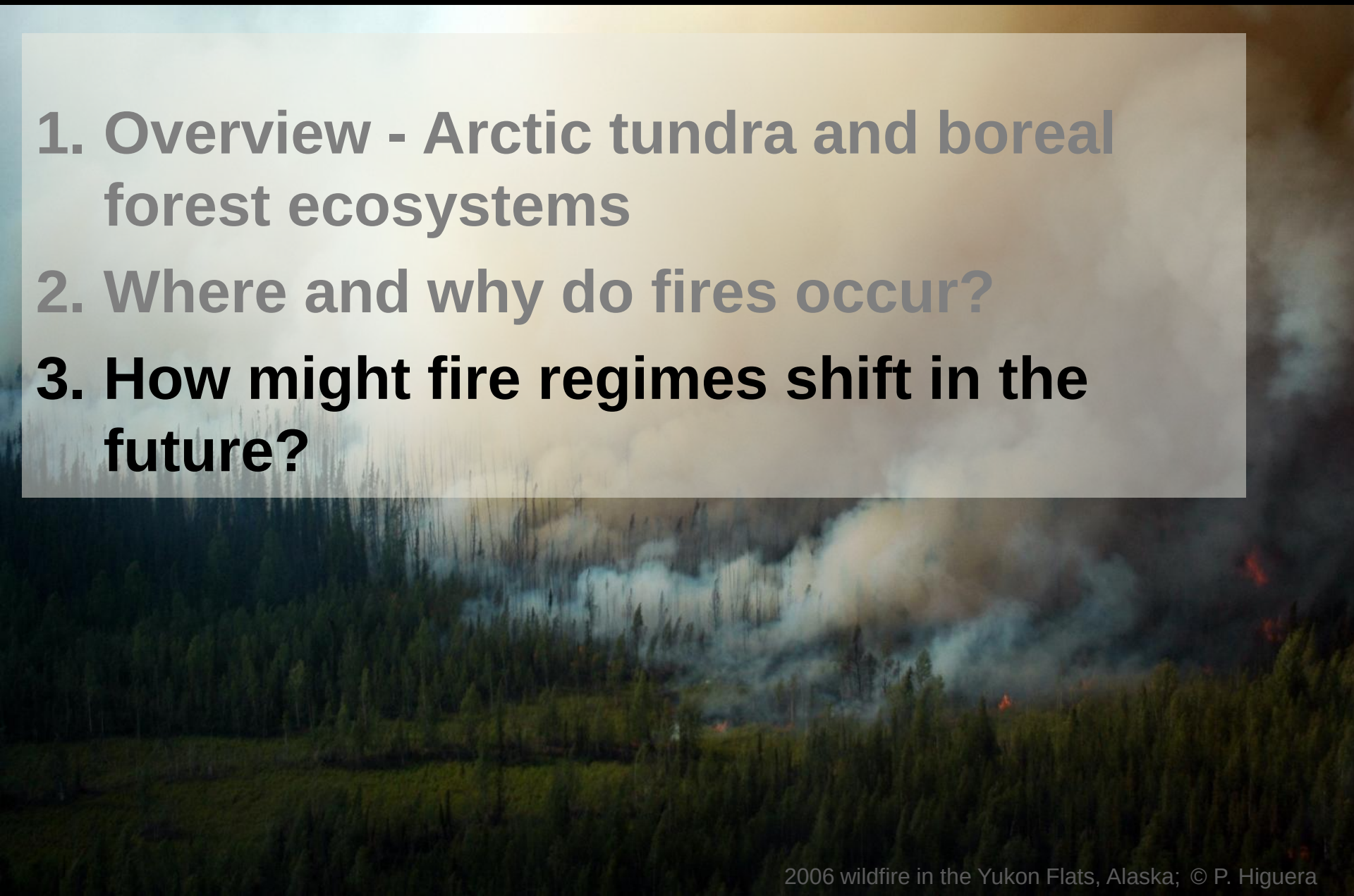
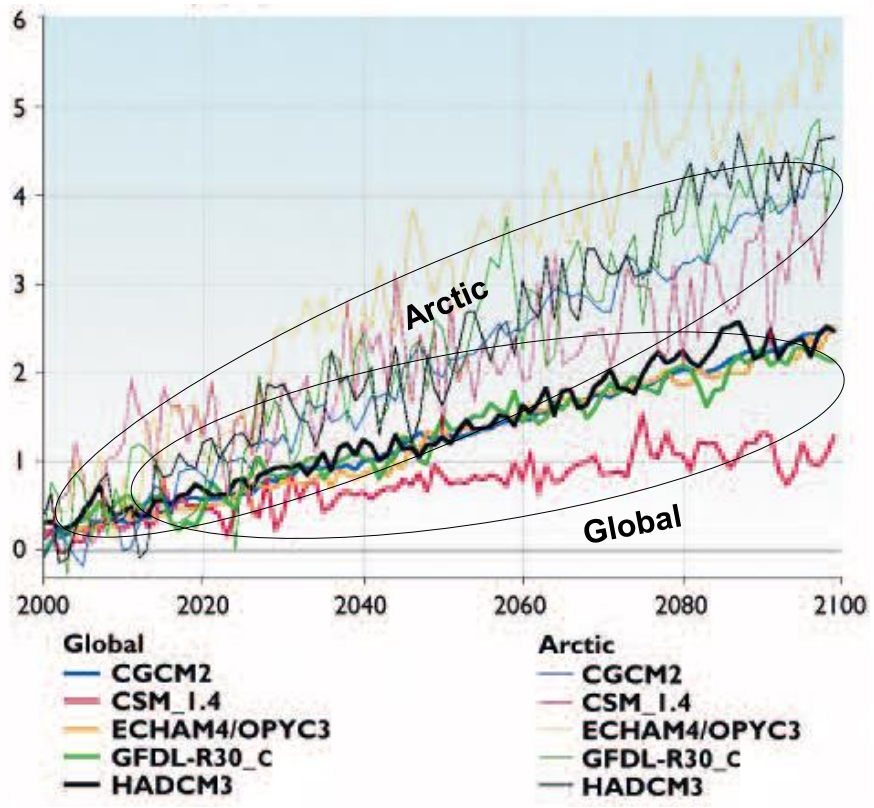


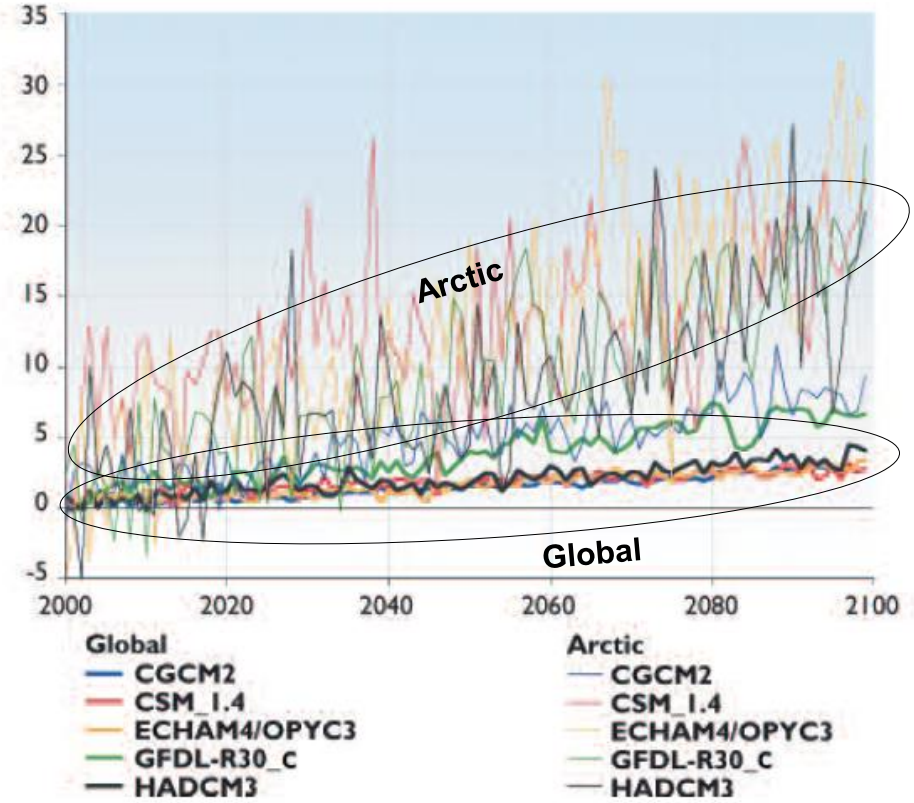
2006 wildfire in the Yukon Flats, Alaska; © P. Higuera

Future changes in climate

Temperature Change (°C)



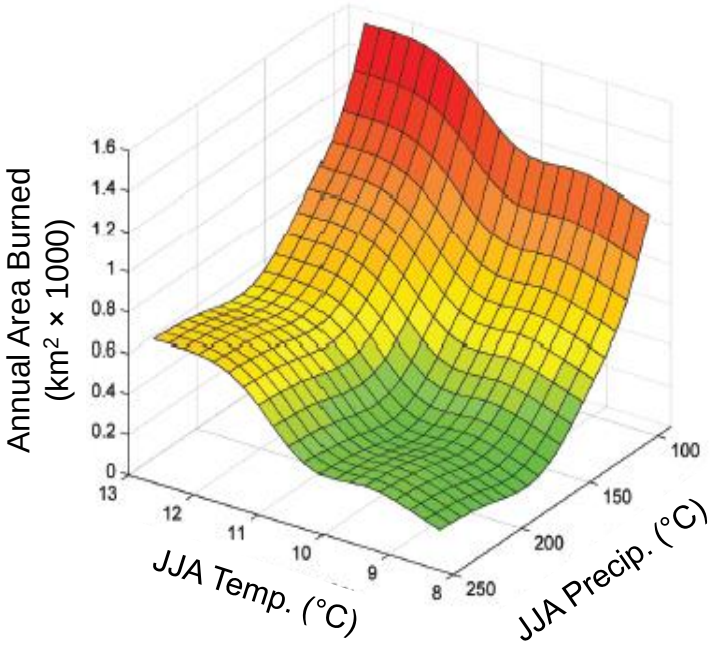
Precipitation Change (%)

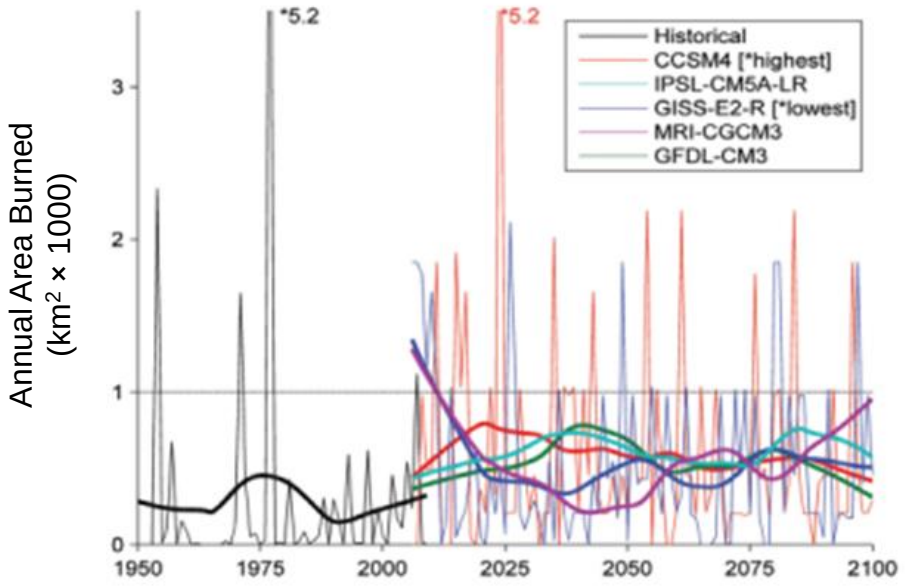


ACIA. 2004

Climate change and wildfire

Projected changes in annual area burned

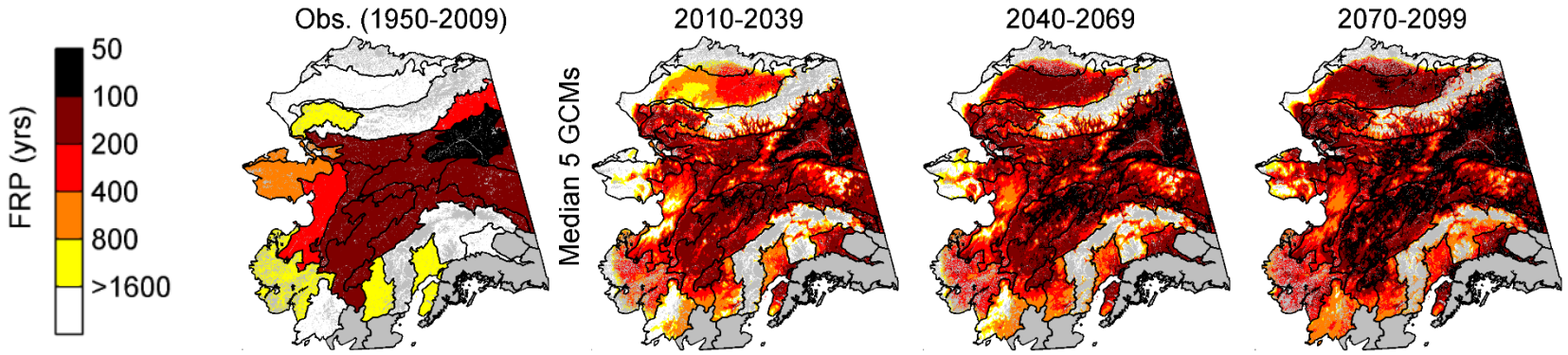




- **Increase in the number of large (>1000 km^2) fire years in AK tundra**

Hu *et al.* 2015 *Front Eco Env*

Projecting future fire activity



FRP = *Fire rotation period

- **Climate projected to be more conducive to wildfire during 21st-century**
- **Shifts to a more active fire regime**

Limitations to projecting future fire activity

What is not considered?

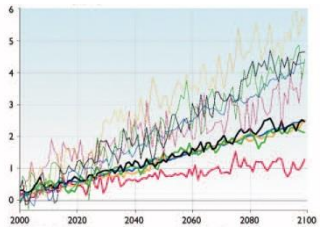
1. ***Changing vegetation***

2. ***Changing ecosystem dynamics (e.g. permafrost thaw)***

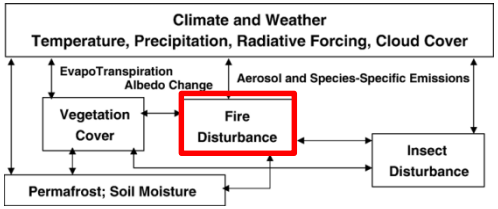
3. ***Changing fire-climate relationships***

Summary – Fire in the Far North

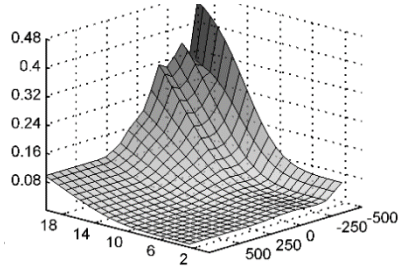
- Climate is rapidly changing and permafrost soils are vulnerable



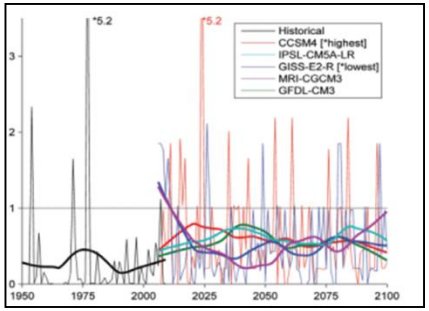
- Fire can play a key role in boreal forest and tundra ecology



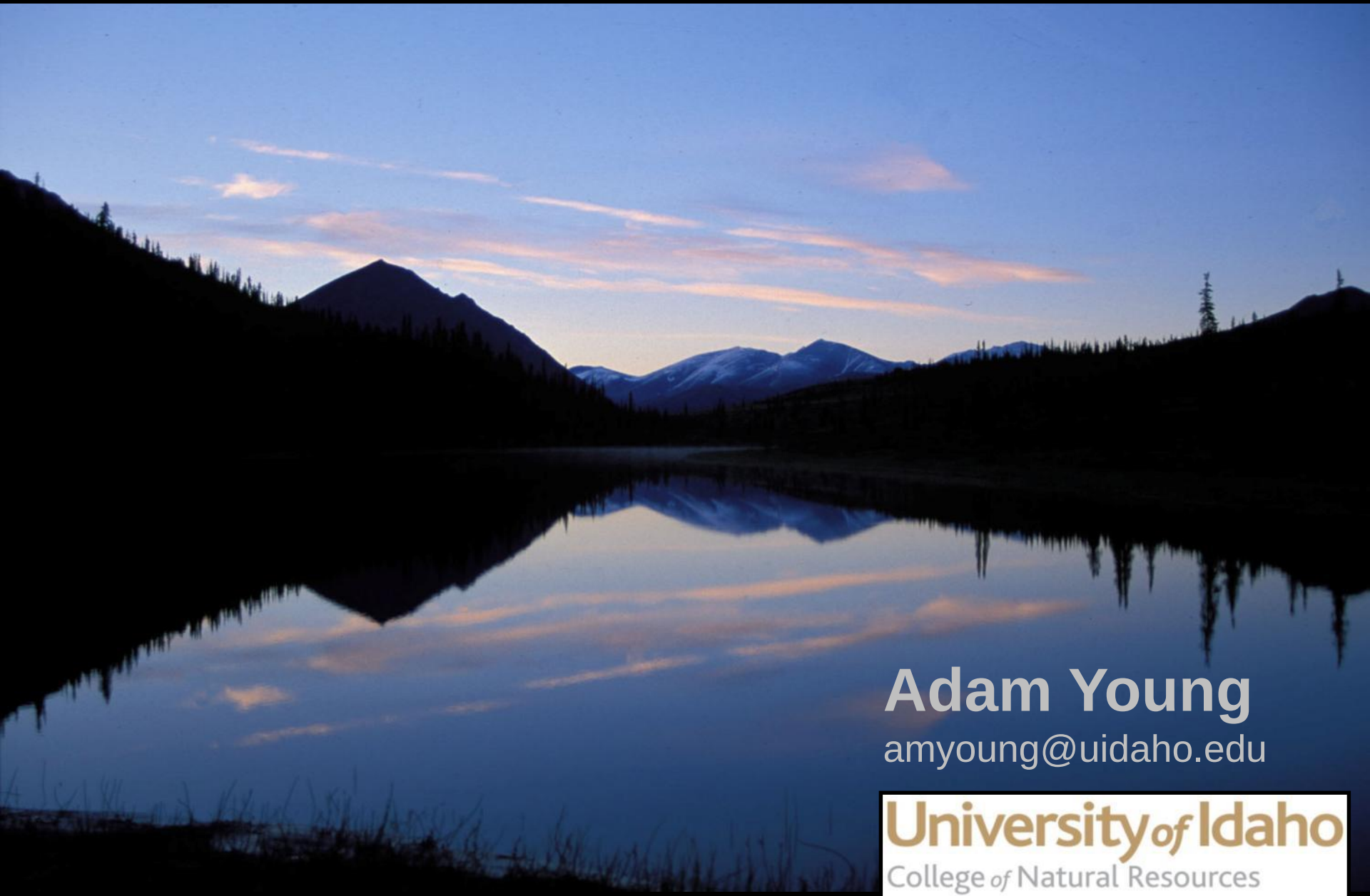
- Fire-regimes shaped by climatic thresholds and interactions



- 21st-century projections suggest fire activity is going to increase in the future



Questions?



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Footprint Lake, Brooks Range, 1 am. © P. Higuera